Fermilab Science Strategy

with a High Intensity Proton Source

Project X

Young-Kee Kim

FRA Visiting Committee Meeting

April 25-26, 2008

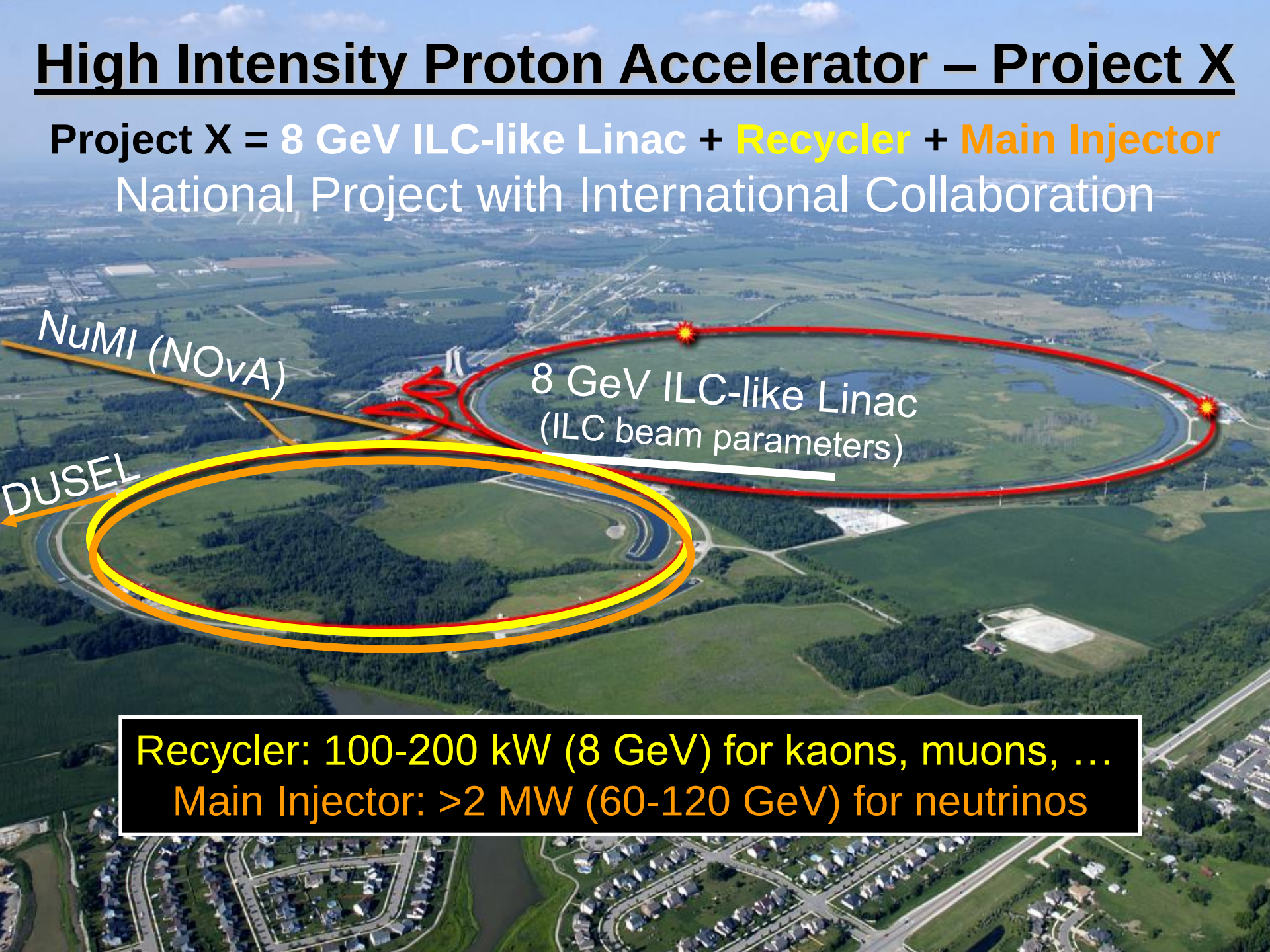
Draft Golden Book for Physics and Experiments

http://www.fnal.gov/directorate/Longrane/Steering_Public/P5.html

High Intensity Proton Accelerator – Project X

Project X = 8 GeV ILC-like Linac + Recycler + Main Injector

National Project with International Collaboration

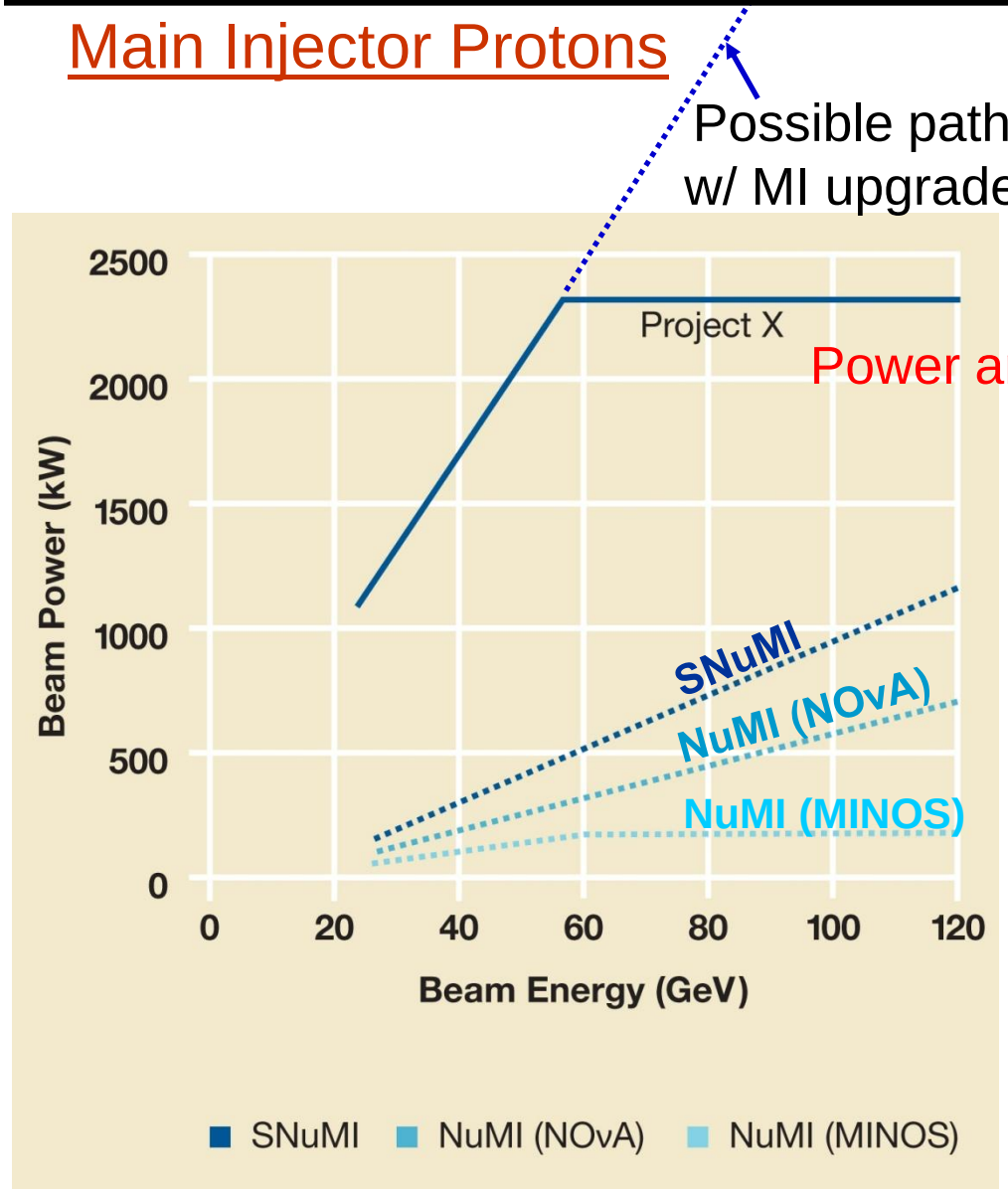


Recycler: 100-200 kW (8 GeV) for kaons, muons, …

Main Injector: >2 MW (60-120 GeV) for neutrinos

Project X: Proton Beam Power

Main Injector Protons



Available 8 GeV Protons

with > 2 MW
60-120GeV MI protons

100-200 kW (Project X)

Power and Flexibility

0* (SNuMI)

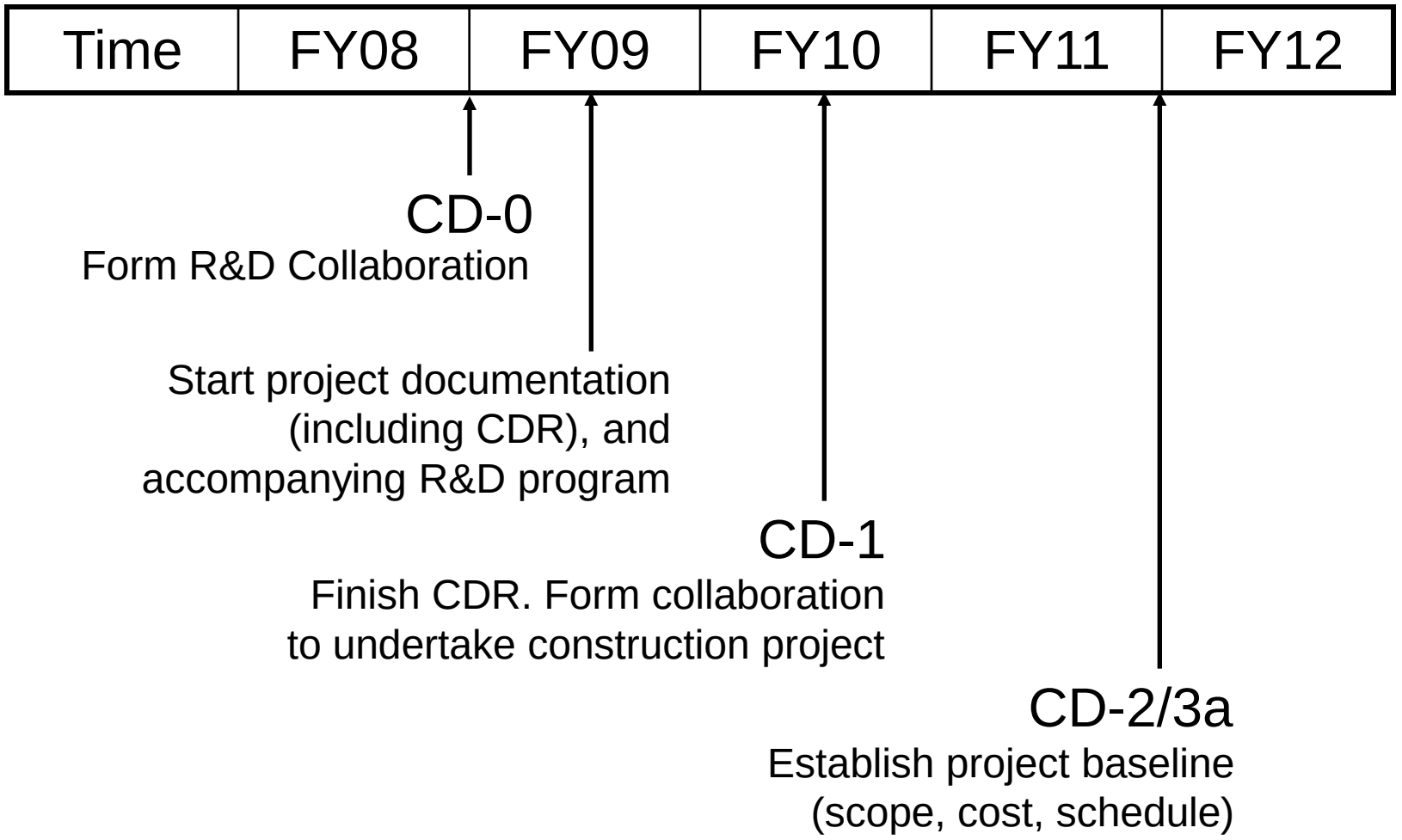
16 kW (NuMI-NOvA)

17 kW (NuMI-MINOS)

35-year-old injection
(technical risk)

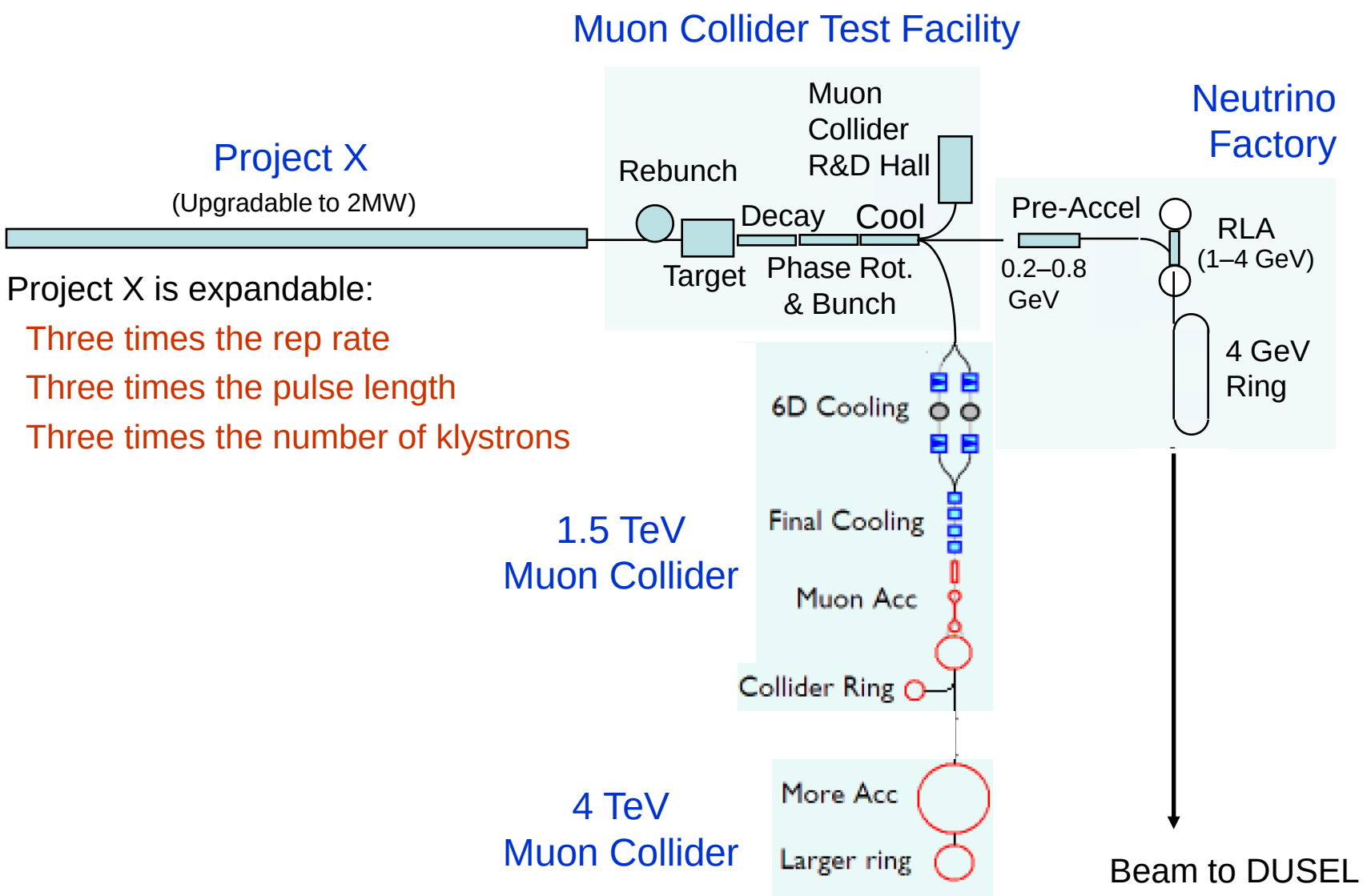
* Protons could be made available at the expense of 120 GeV power.

Project X Accelerator R&D Goals



[David McGinnis's Talk on "Project X R&D"]

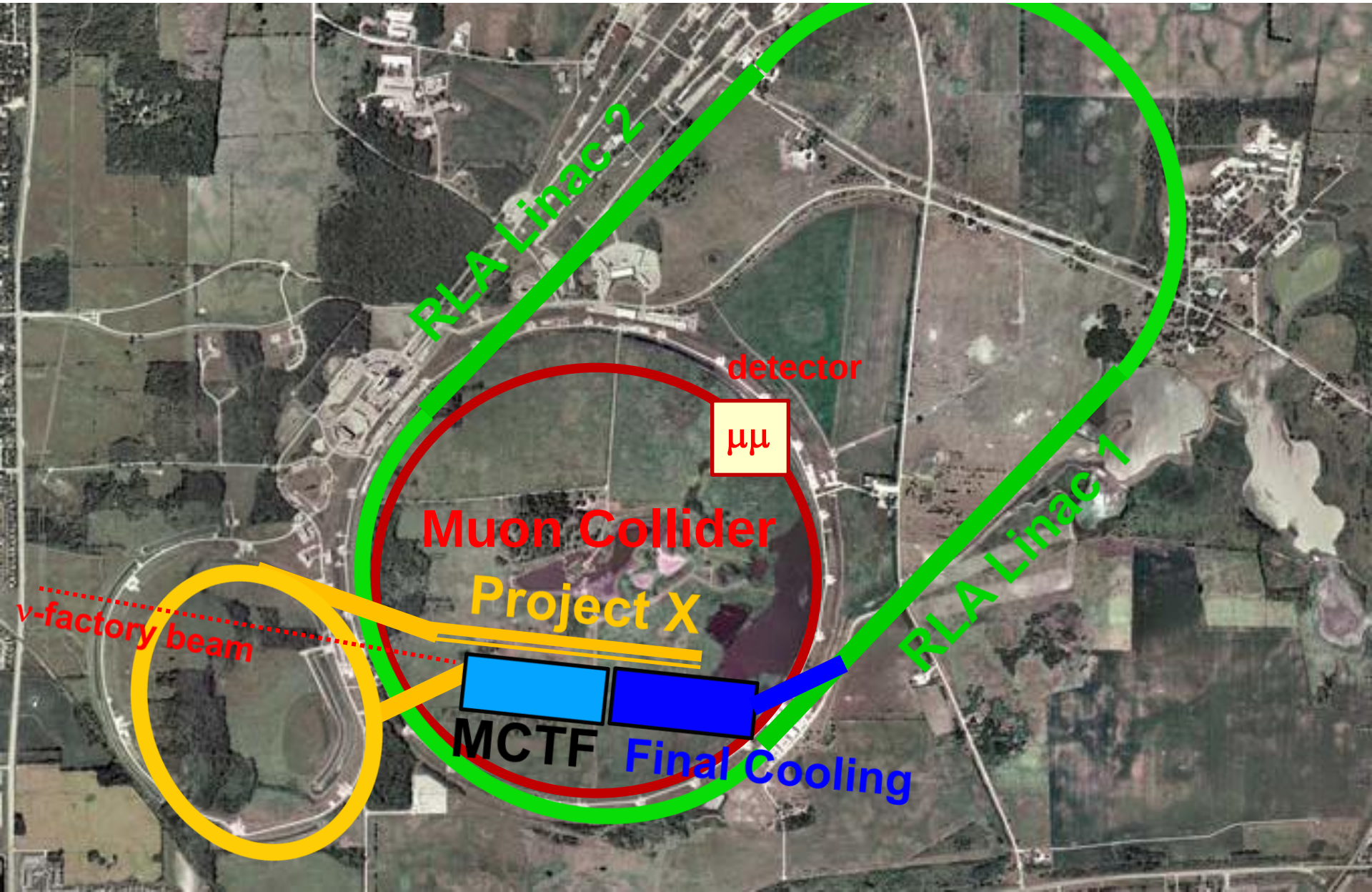
Evolutionary Path to ν-Factory & $\mu^+\mu^-$ Collider



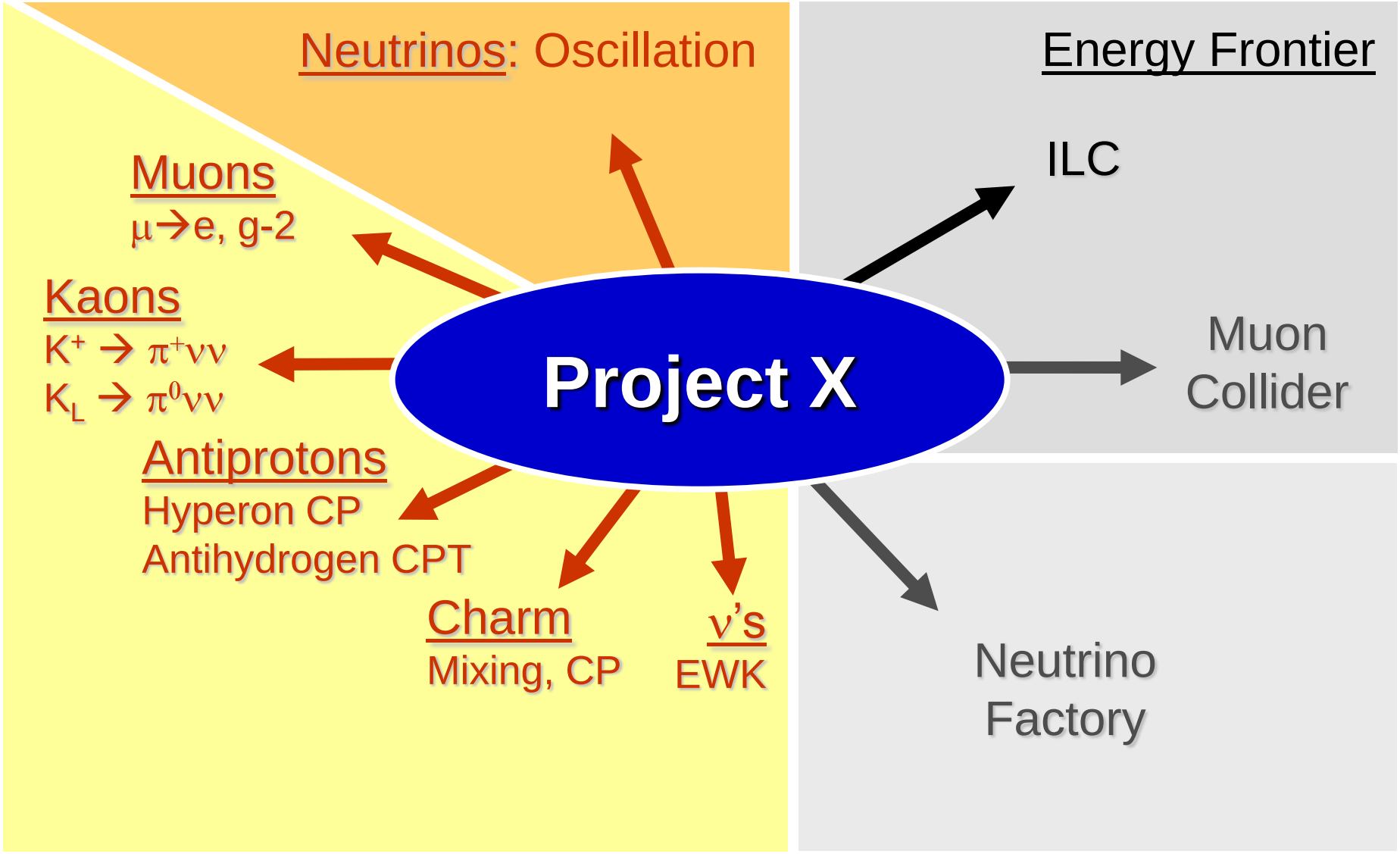
Project X is expandable:

- Three times the rep rate
- Three times the pulse length
- Three times the number of klystrons

Evolutionary Path to "$\mu^+\mu^-$ Collider"

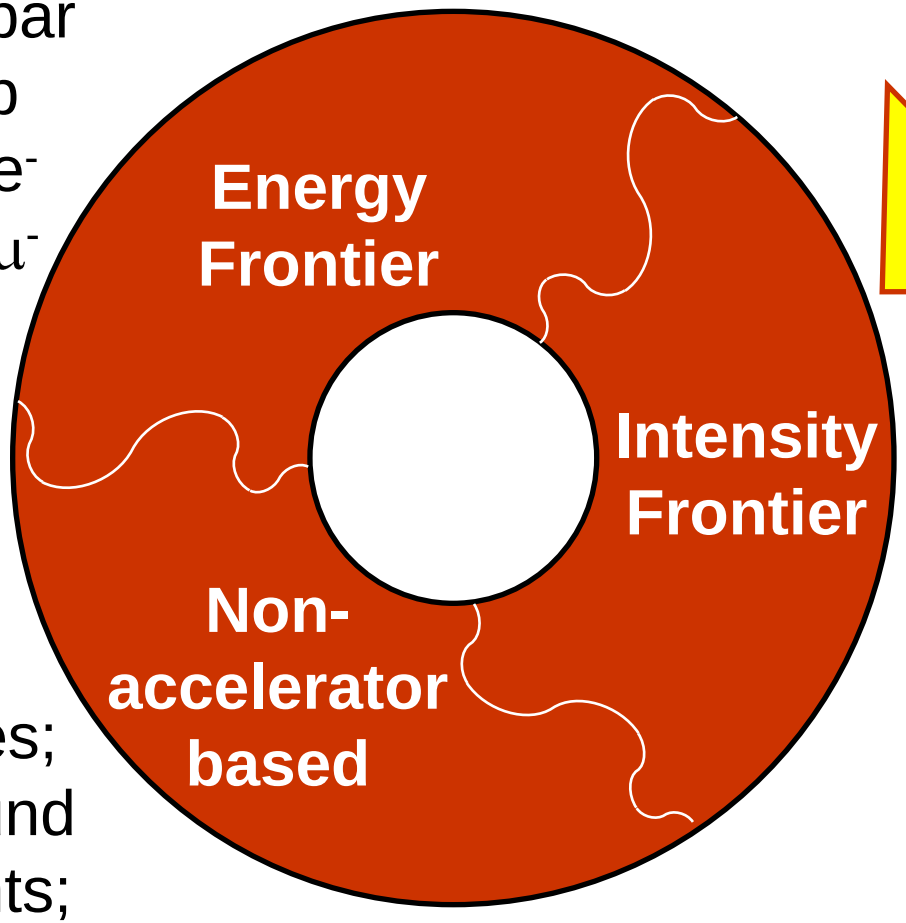


Opportunities with Project X



Tools for Particle Physics

pp-bar
pp
e^+e^-
$\mu^+\mu^-$



Project X for Physics of Flavor

Intense proton source for
ν, μ, K, $\bar{p}$ beams;

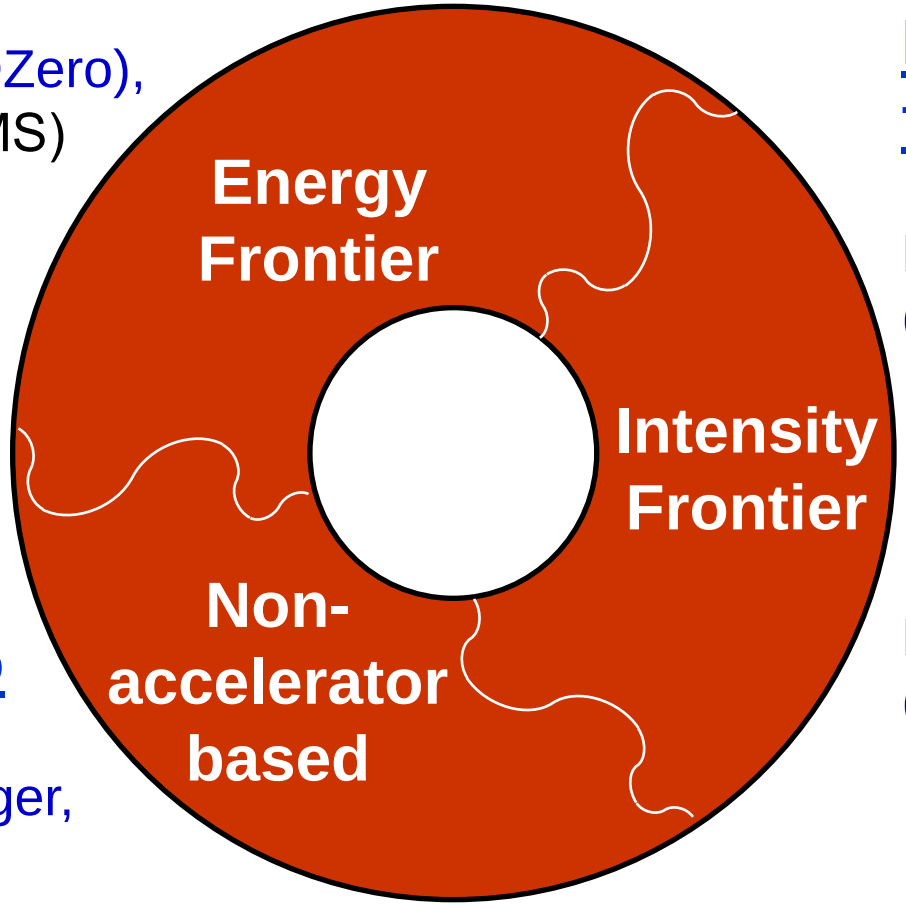
B, C factories

Telescopes;
Underground experiments;
…..

Tools at Fermilab

Colliders

Tevatron (CDF, DZero),
"LHC" (Accel, CMS)
ILC R&D
μ Collider R&D



Proton Sources for Neutrinos

Main Injector
(120GeV protons)
- MINOS
- NOvA
- MINERvA

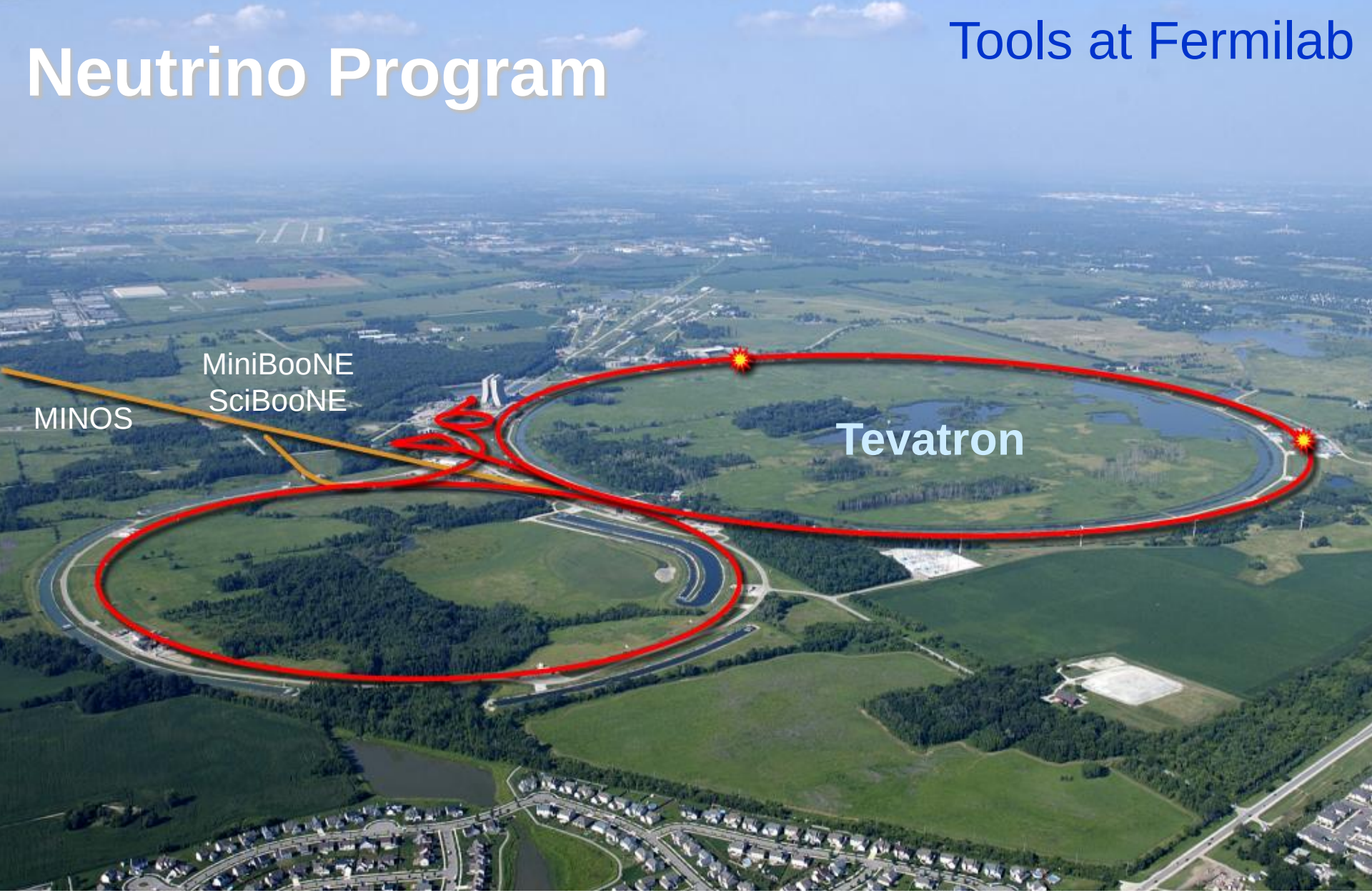
Booster
(8GeV protons)
- MiniBooNE
- SciBooNE

Particle Astro

SDSS, Pierre Auger,
CDMS, COUPP,
DES, SNAP R&D

Neutrino Program

Tools at Fermilab



Debbie Harris's talk on "Neutrino Physics Overview"

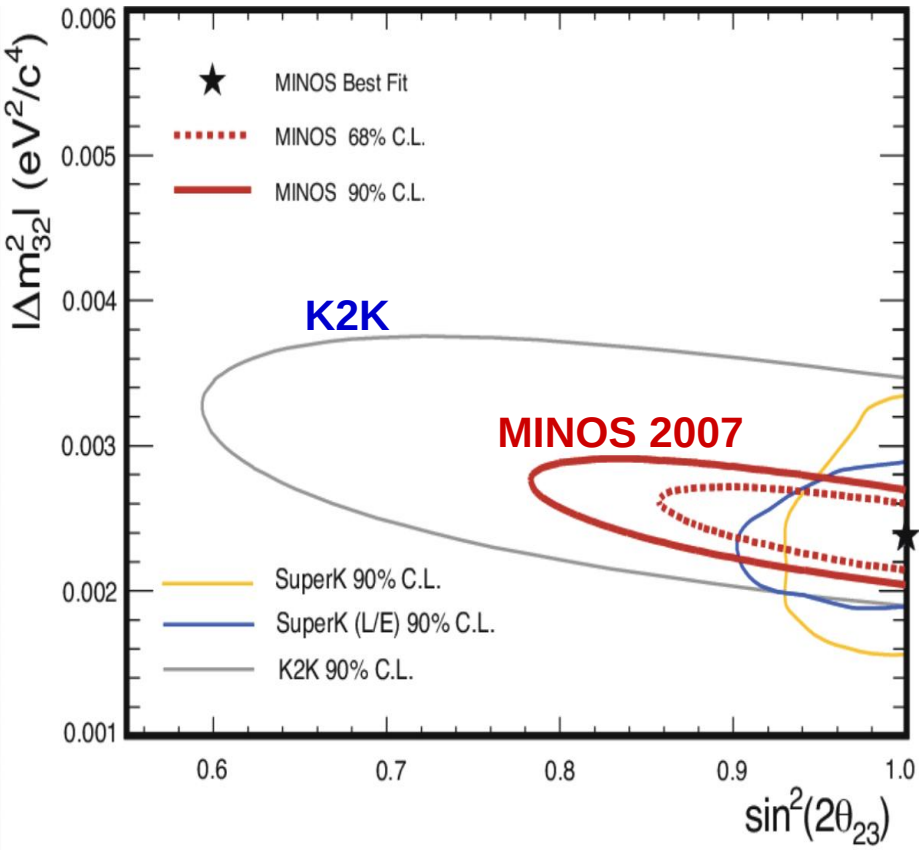
AIP's Ten Top Physics Stories for 2007

- Three out of ten are from Particle / Particle Astro:
  - The Tevatron, in its quest to observe the Higgs boson, updated the top quark mass and observed several new types of collision events, such as those in which only a single top quark is made, and those in which a W and Z boson or two Z bosons are made simultaneously. http://www.aip.org/pnu/2007/split/821-1.html
  - The MiniBooNE experiment at Fermilab solves a neutrino mystery, apparently dismissing the possibility of a fourth species of neutrino.

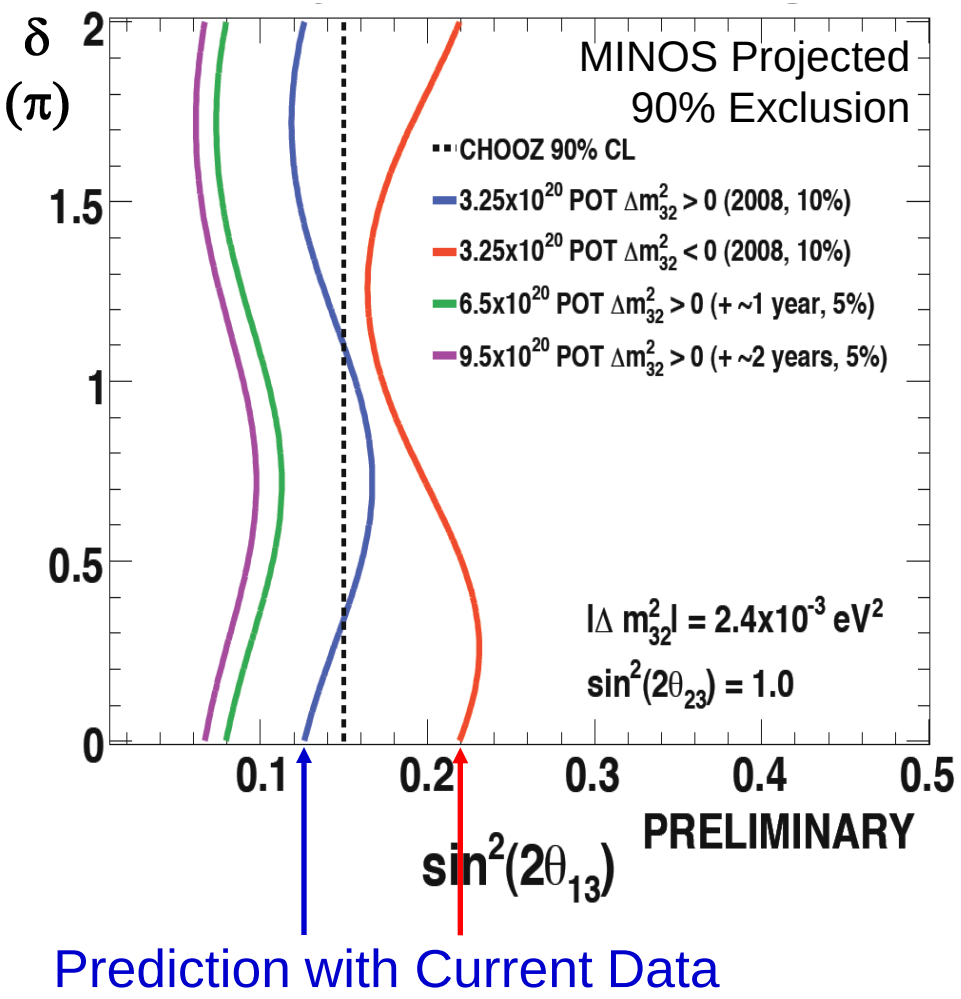
    http://www.aip.org/pnu/2007/split/820-1.html
  - Based on data recorded at the Auger Observatory, astronomers conclude that the highest energy cosmic rays come from active galactic nuclei. http://www.aip.org/pnu/2007/split/846-1.html

MINOS

Best Δm^2_{32} measurement



Probing $\sin^2(2\theta_{13})$



Prediction with Current Data

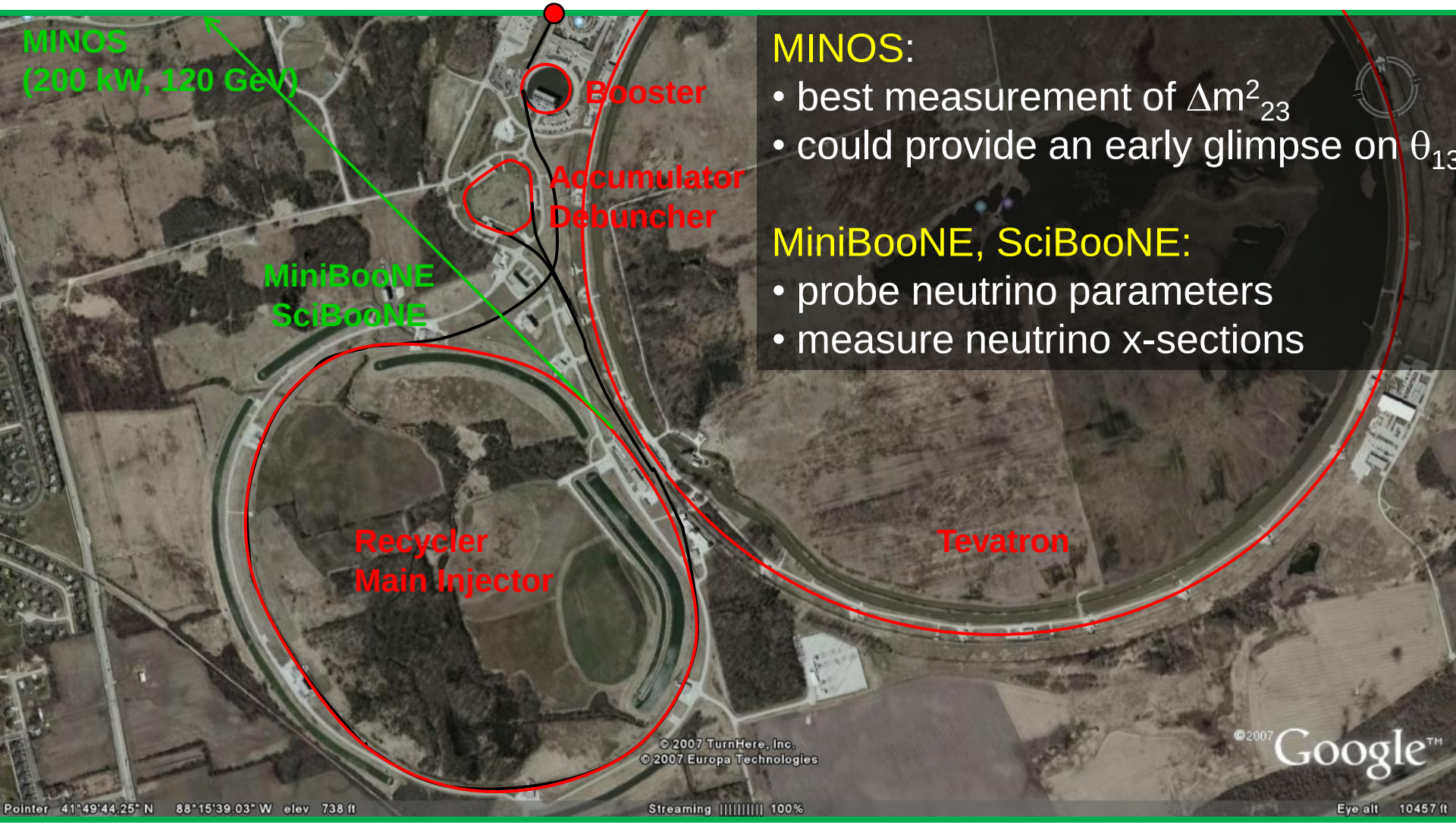
Neutrino Vision at Fermilab

"World-Leading Neutrinos" as a Flagship Program

By developing
a phased approach with
ever increasing beam intensities
and ever increasing detector capabilities

Neutrino Mixing, Mass Ordering, CP Violation

Present: World-leading neutrino program



Phase 1: World-leading neutrino program

NOvA:

- provide the first glimpse of the mass hierarchy for large θ_{13} - the only near term probe of hierarchy in the world
- great sensitivity to θ_{13}

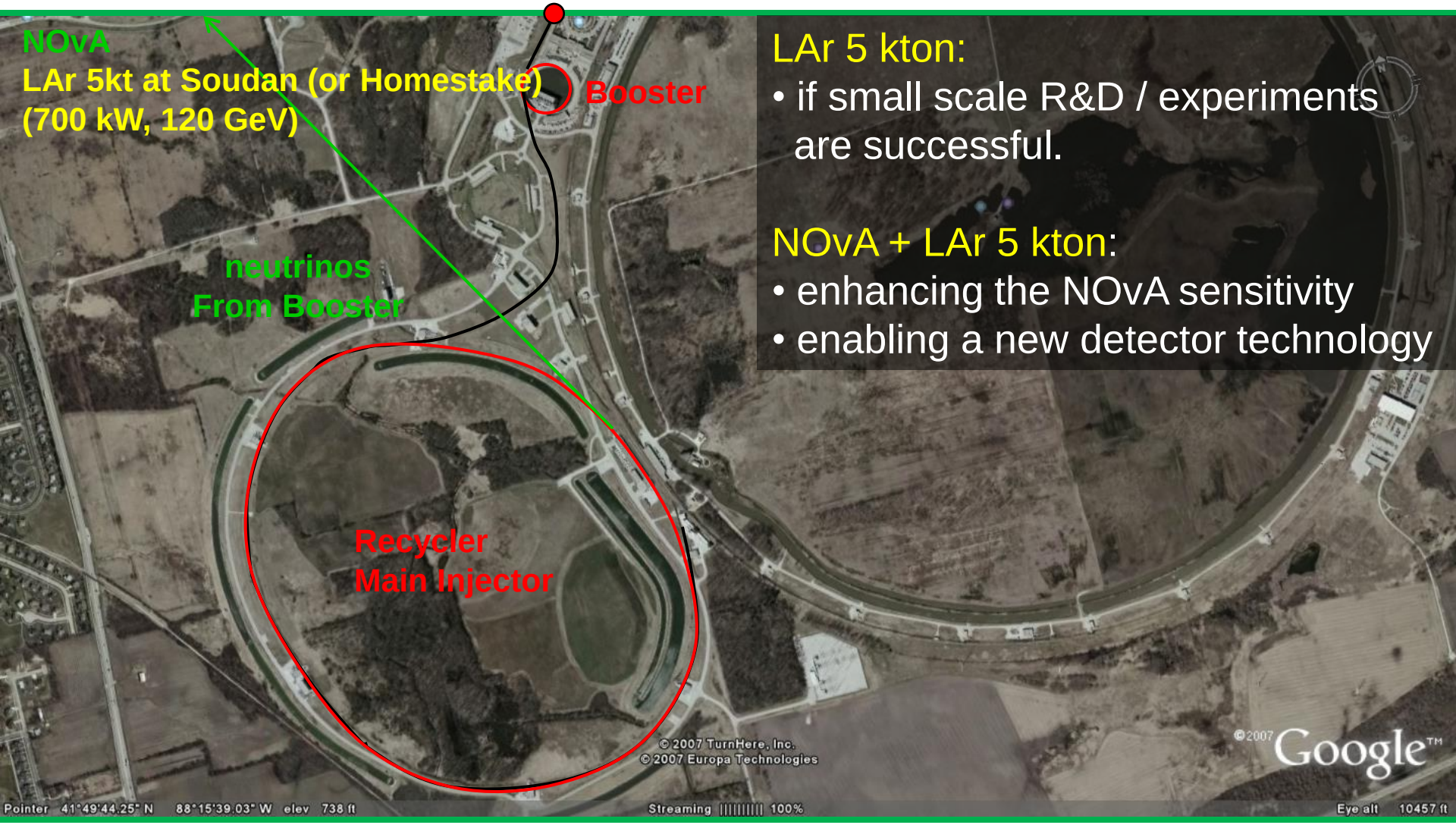
MINERvA:

- measure neutrino x-sections (above 1 GeV) to high precision

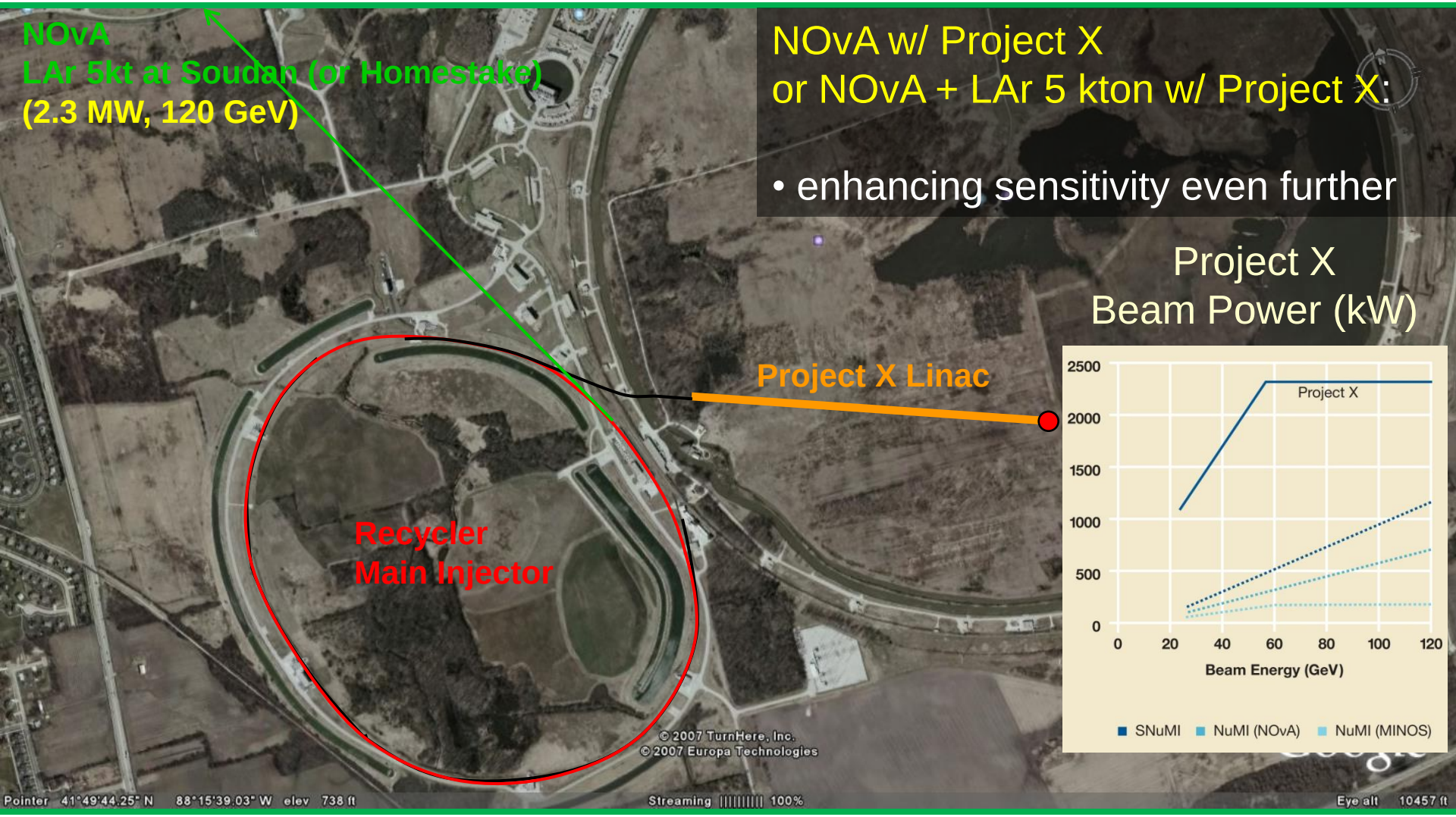
MicroBooNE(?)

- small scale LAr R&D/physics expt.

Phase 1.5: World-leading neutrino program



Phase 2: World-leading neutrino program



Phase 3

World-leading neutrino program (World-leading proton decay program)

Project X beam to DUSEL:

- enhancing the sensitivity markedly

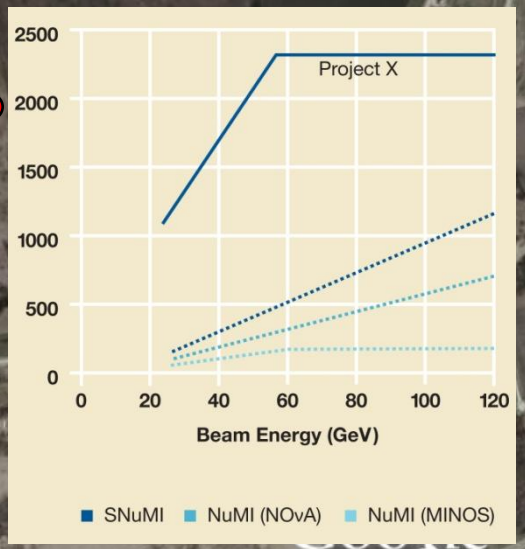
DUSEL (WC or/and LAr)
(>2 MW, 50 – 120 GeV)

(ν Detector = Proton Decay Detector)

Recycler
Main Injector

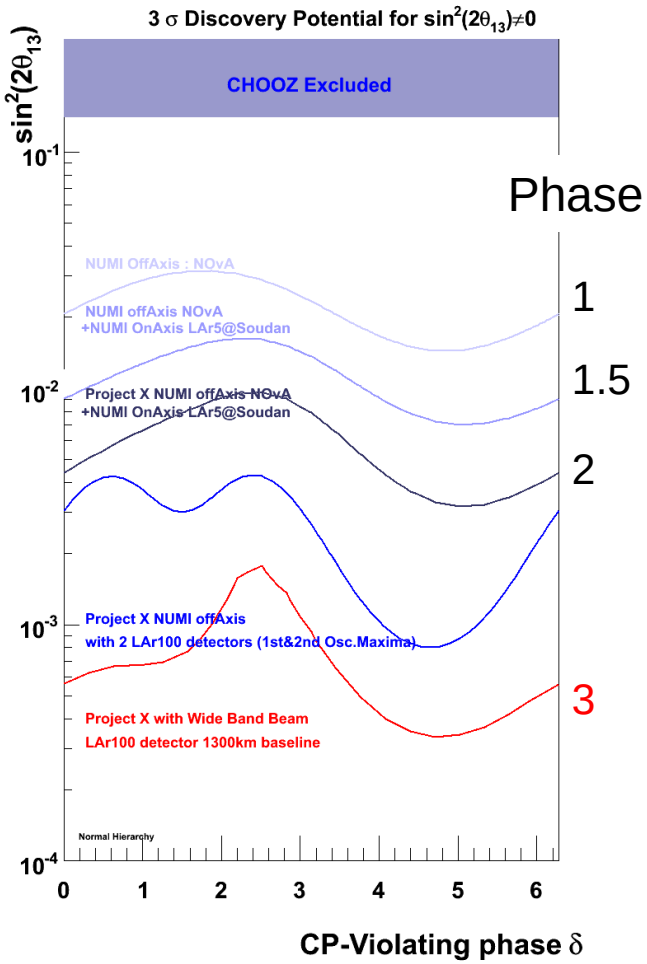
Project X Linac

Project X
Beam Power (kW)

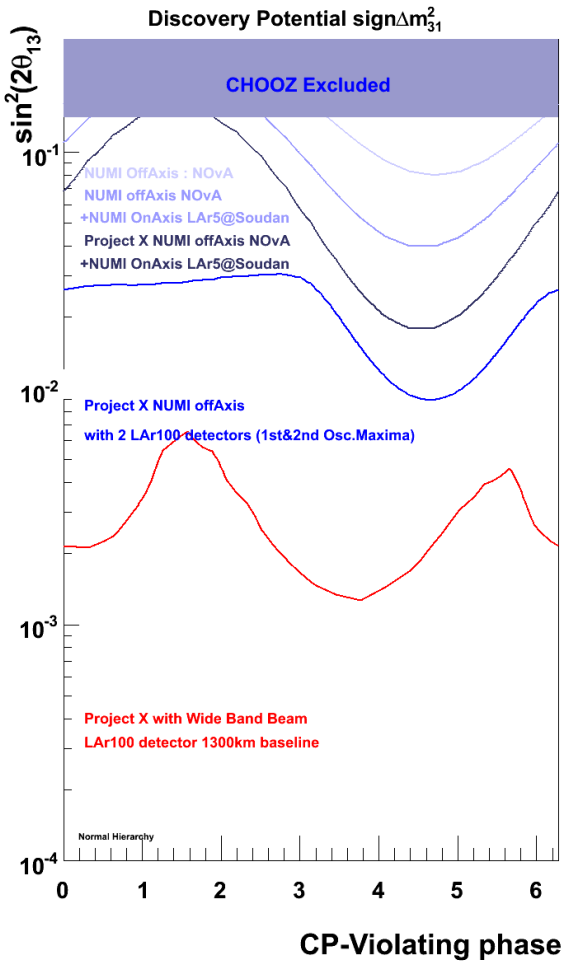


The 3σ Reach of the Successive Phases

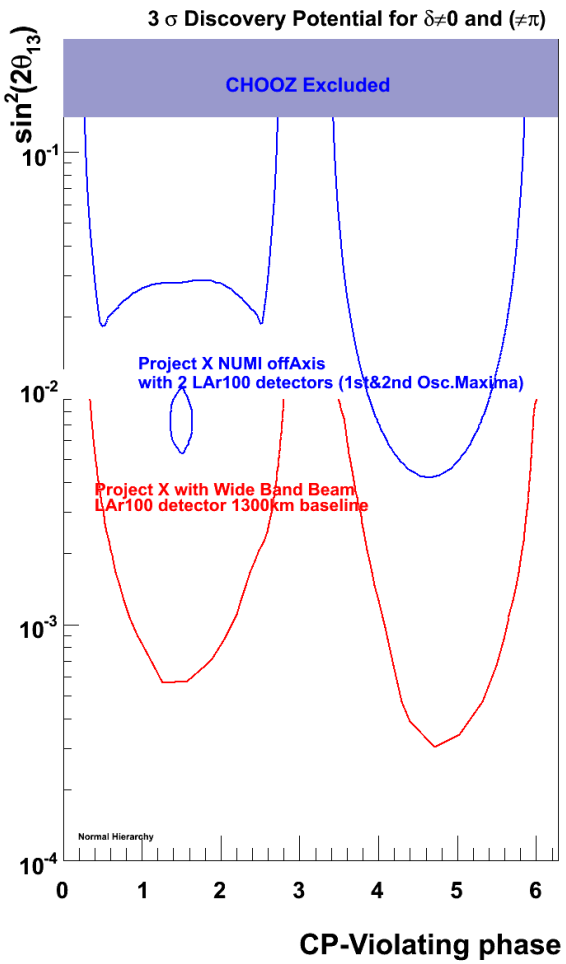
$\sin^2 2\theta_{13}$

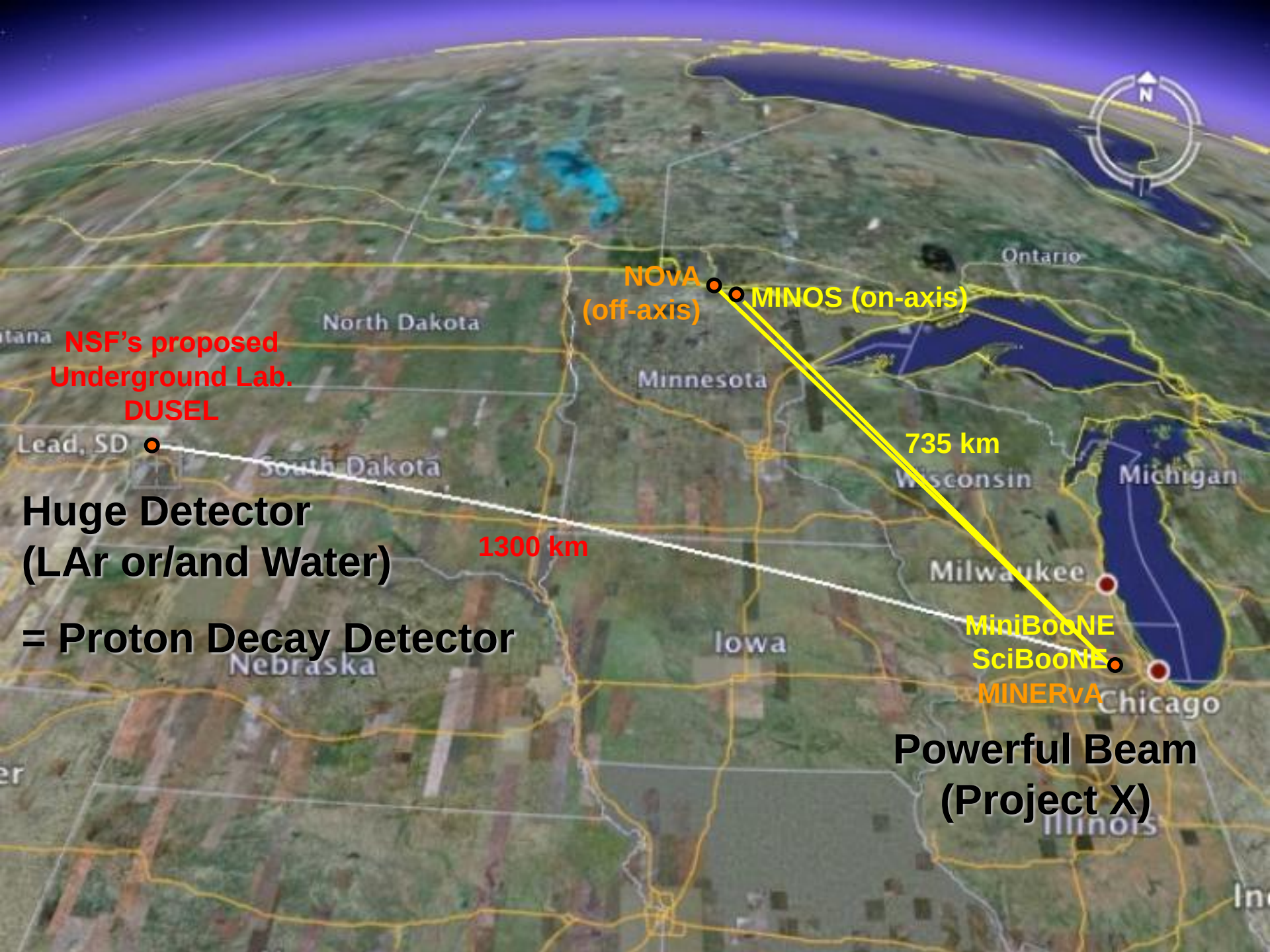


Mass Ordering



CP Violation




NOvA
(off-axis)
MINOS (on-axis)
NSF's proposed
Underground Lab.
DUSEL
Lead, SD
735 km
1300 km
Huge Detector
(LAr or/and Water)
= Proton Decay Detector
MiniBooNE
SciBooNE
MINERvA
Powerful Beam
(Project X)
North Dakota
Minnesota
South Dakota
Nebraska
Iowa
Wisconsin
Michigan
Ontario
Milwaukee
Chicago
Illinois
N

DUSEL Beamline Working Group

- Charge
  - To develop plans for a beamline to the DUSEL in Homestake, South Dakota.
- Group
  - Mike Andrews, Jeff Appel (chair), Dixon Boert, Sam Childress, Bill Griffing, Nancy Grossman, Dave Harding, Jim Hylen, Vic Kuchler, Chris Laughton, Mike Martens, Elaine McCluskey, Rob Plunkett, Gina Rameika, Gueorgui Velev, Bob Zwaska
- First meeting on April 30

LAr TPC R&D Director's Review

- Charge
  - To review proposed liquid argon TPC R&D towards a ~ 100 kton detector
    - Liquid Argon TPCs show promise as scalable devices for the large detectors needed for long baseline neutrino oscillation physics. Over the last several years a staged approach to developing the technology for large detectors has been developed. A specific plan with the ~200 ton MicroBooNE detector and the ~5000 ton LAr5 detector as the key elements emerged with the presentations of these detectors to the Fermilab PAC.

      Please evaluate this specific approach as a path to a ~100 kton LArTPC detector mass. In particular, are the proposed R&D programs, in the context of other initiatives worldwide, effective steps towards large detectors?
- Review Panel
  - Daniel Fournier, Bob Kephart (chair), , Taka Kondo, Alberto Marchonni, Harry Weerts
- Review Date
  - June 3
- Input to the next PAC meeting on June 17-22

Neutrinos

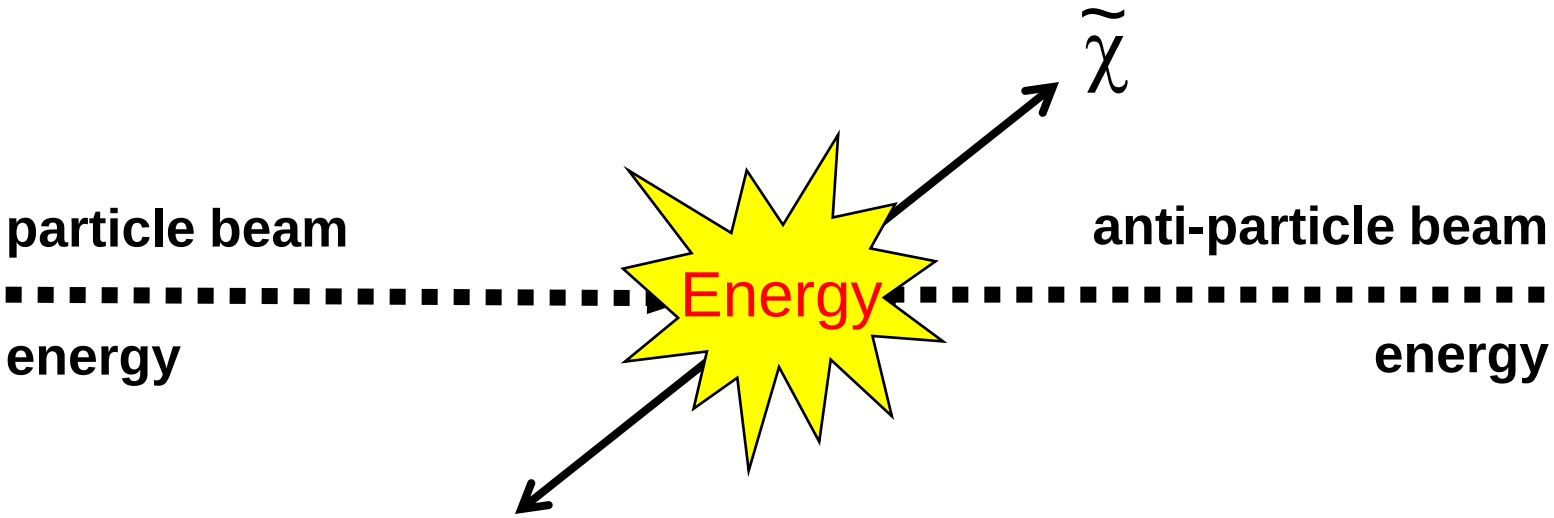
Flagship Program

Charged Leptons and Quarks

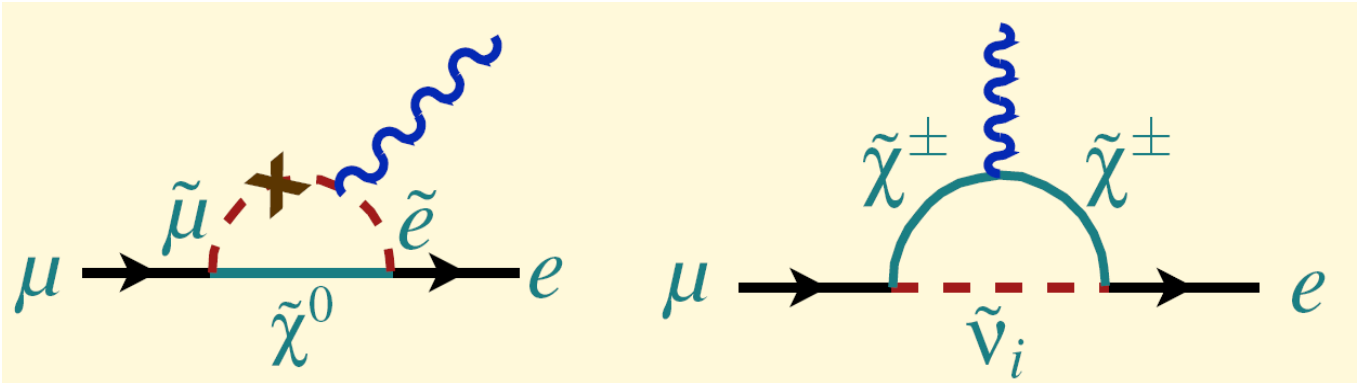
(without reducing neutrino beam power)

→ via International Coordination / Collaboration

“Relativistic Path” with Energy Frontier Facility



“Quantum Path” with Intensity Frontier Facility



Charged Leptons and Quarks

- Connection to LHC and Beyond
  - If the LHC discovers new particles,
    - Precision flavor physics experiments will help determine their nature
  - If the LHC does not discover new particles,
    - Flavor physics processes with negligible rates in the SM are the only way to probe higher energies.
  - Whatever the LHC sees,
    - Flavor physics processes can access energies well beyond those of the LHC.

Charged Lepton Flavor Violation

Neutrinos change from one kind to another.

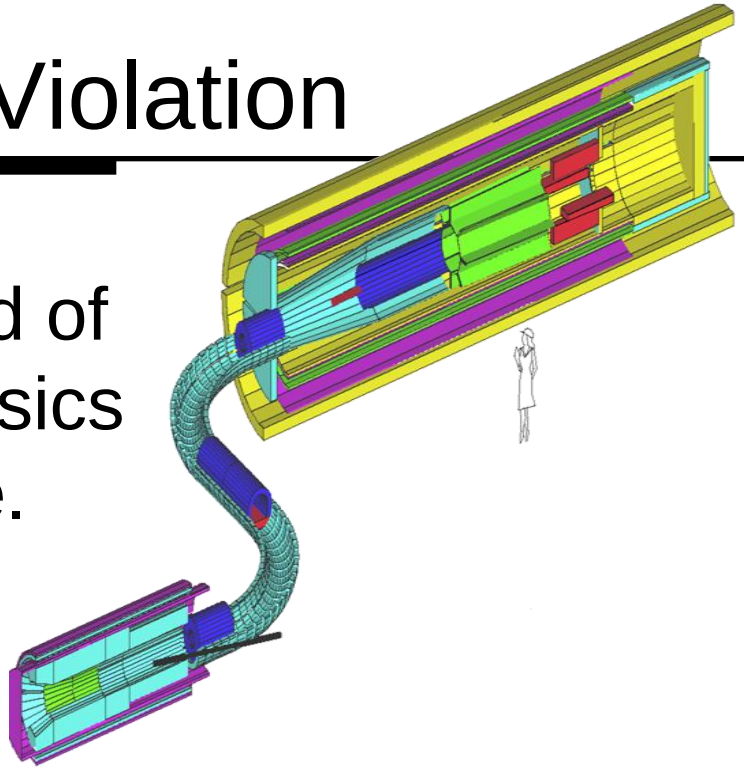
Do charged leptons do, too?

Matter Unification

Do all particles come from a single kind of superparticle in the first instant of the big bang?

Charged Lepton Flavor Violation

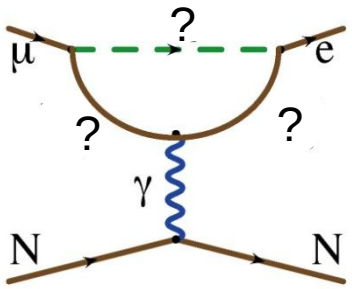
μ → e conversion in the field of a nucleus is sensitive to physics at a very high mass scale.

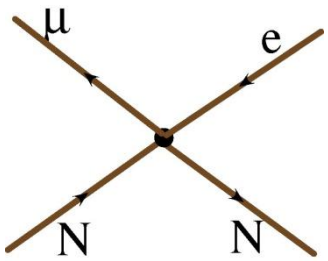


Parameterizing relative strength of dipole and 4-fermi interactions

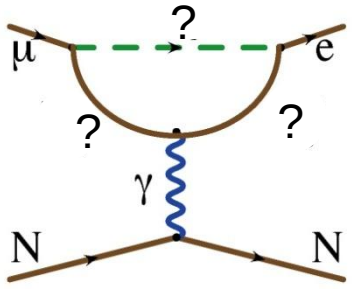
$$L_{CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left\{\sum_{q=u,d}\bar{q}_L\gamma^\mu q_L\right\}$$

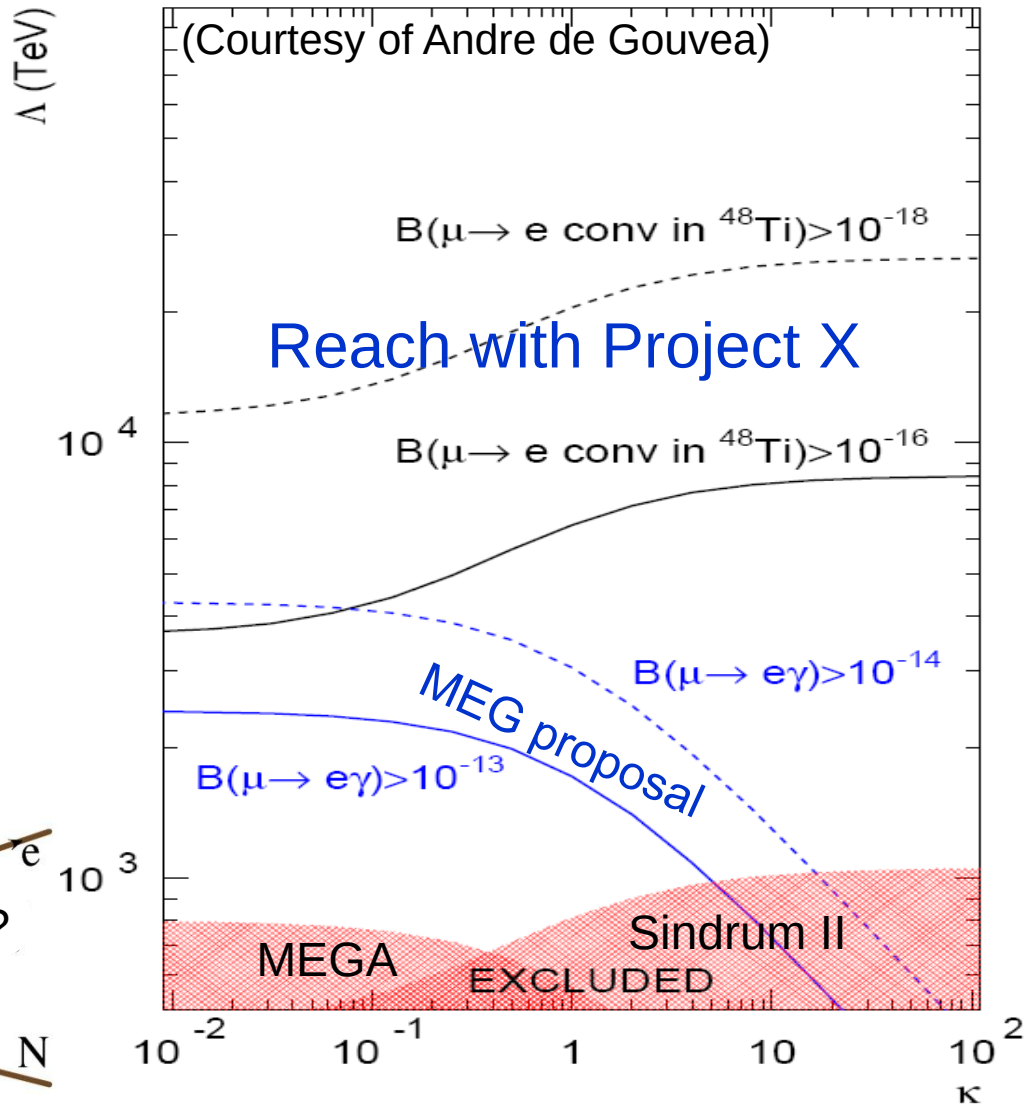
Scale of new physics

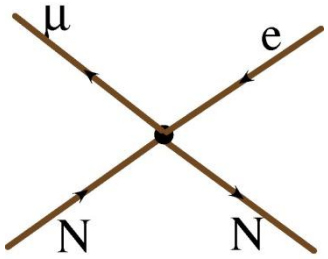




Charged Lepton Flavor Violation







Charged Lepton Flavor Violation

CLFV can be induced by $\tilde{\mu}$ – $\tilde{e}$ mixing in SUSY.

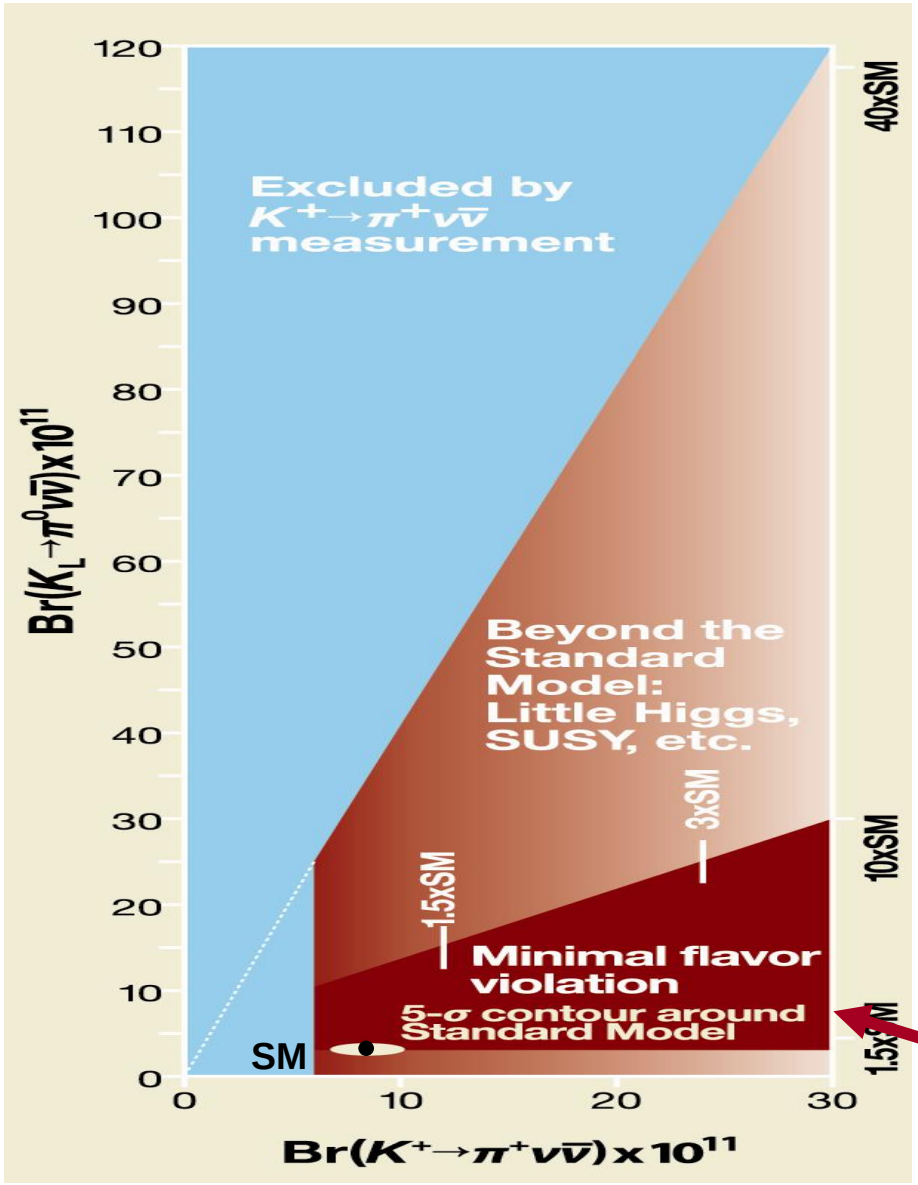
This mixing could lead to large CLFV if neutrino masses come from the See-Saw.

With

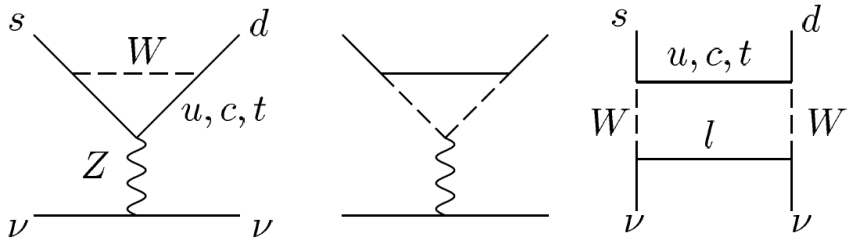
Information on SUSY from LHC
+ Neutrino oscillation results
+ CLFV results
+ Neutrinoless double beta decay measurement

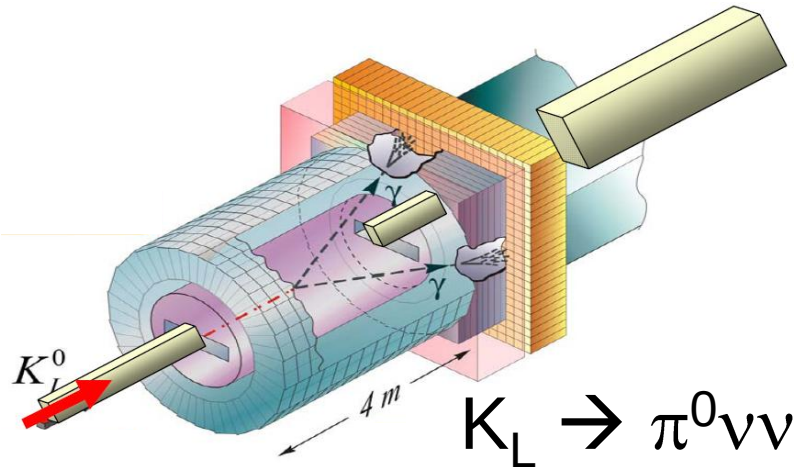
→ Test Leptogenesis

Kaons: Rare Decays $K^+ \rightarrow \pi^+\nu\nu$, $K_L \rightarrow \pi^0\nu\nu$



SM Leading diagrams



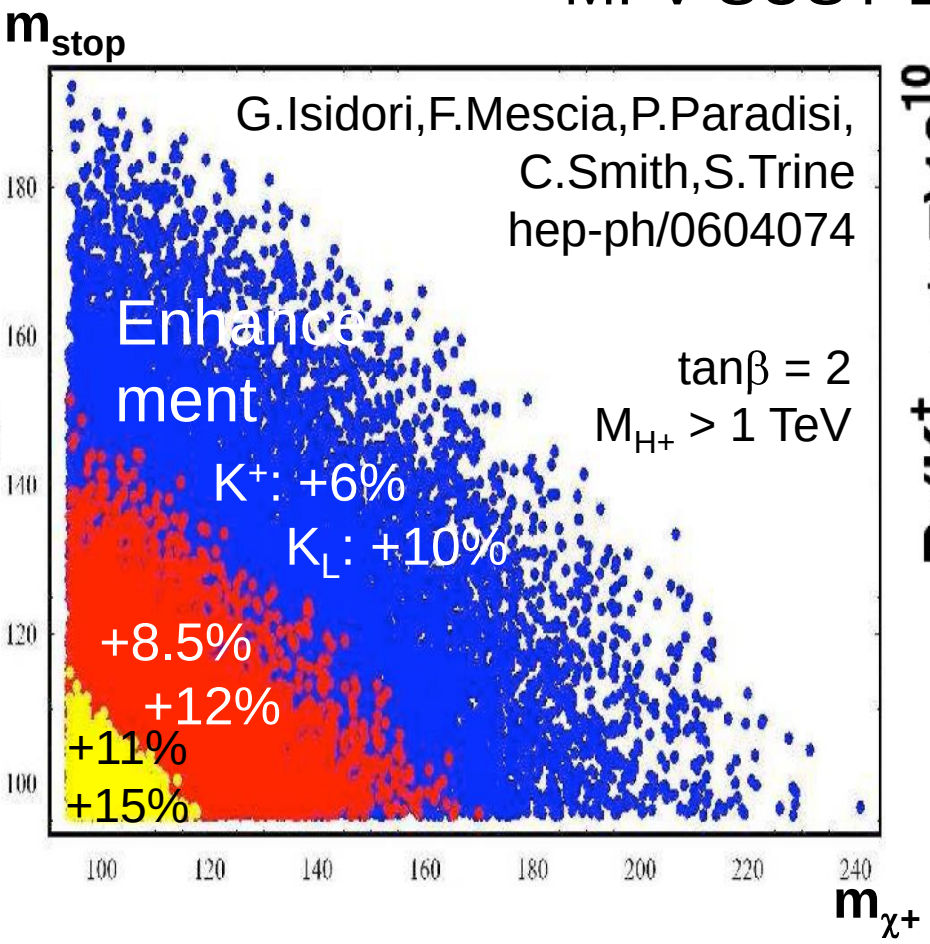


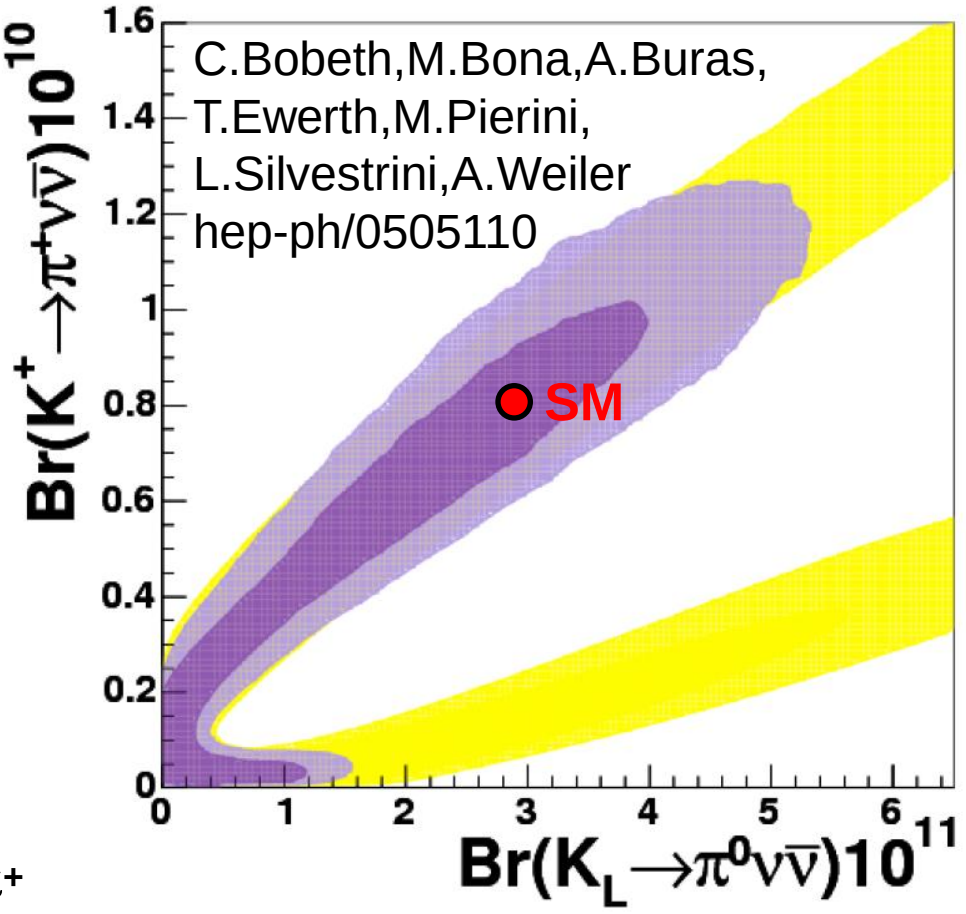
$K_L \rightarrow \pi^0\nu\nu$ Experiment Concept

an almost-MFV World

Kaons: Rare Decays

MFV SUSY Effects on K → πνν





Powerful probe of MFV where enhancements are < ~2.

Kaons: Rare Decays

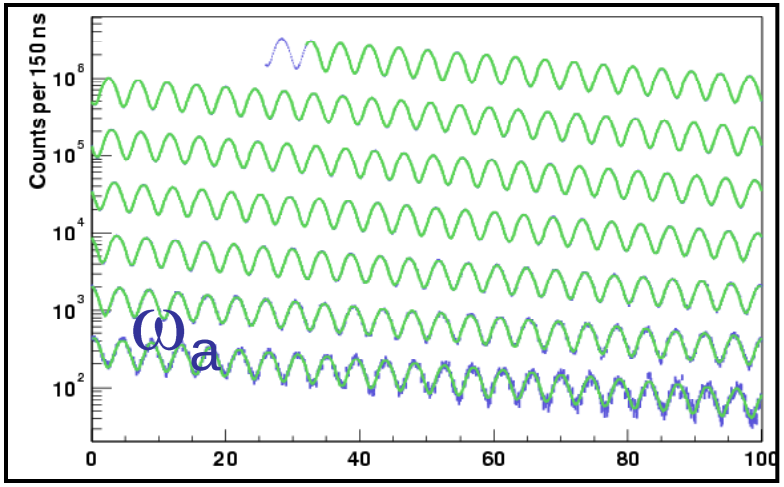
per year

Facility	Duty Factor	Clock hours	Beam hours	Projected # of K → πνν
CERN-SPS (450 GeV)	30%	1420	405	40 (charged)
Booster Stretcher (8GeV, 16kW)	90%	5550	5000	50 (charged)
Tevatron-Stretcher (120 GeV)	90%	5550	5000	200 (charged)
ProjectX Stretcher (8GeV, 200kW)	90%	5550	5000	300 (charged)
JPARC-I (30 GeV)	21%	2780	580	~1 (neutral)
BNL AGS (24 GeV)	50%	1200	600	20 (neutral)
JPARC-II (30 GeV)	21%	2780	580	30 (neutral)
Booster Stretcher (8GeV, 16kW)	90%	5550	5000	50 (neutral)
ProjectX Stretcher (8GeV, 200kW)	90%	5550	5000	300 (neutral)

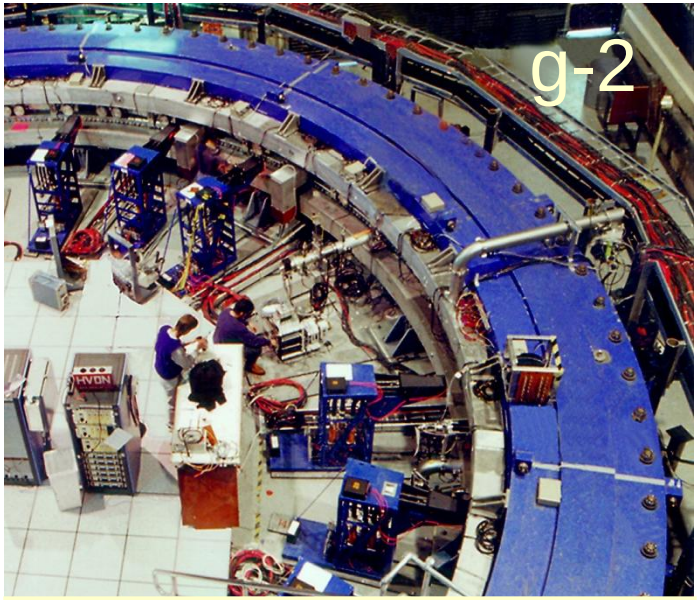
J-PARC - Neutrino:Kaon = 50%:50%

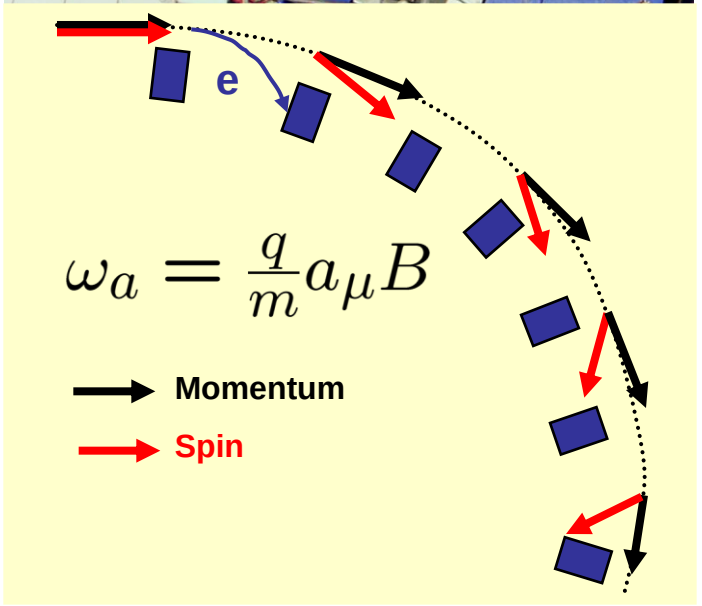
Muons for g-2

- sensitive to a high mass scale
- α_μ is determined from the ratio of muon precession freq.(ω_a) and magnetic field (B).



- With higher precision, could help determine the SUSY parameters
  - tanβ, sign(μ)





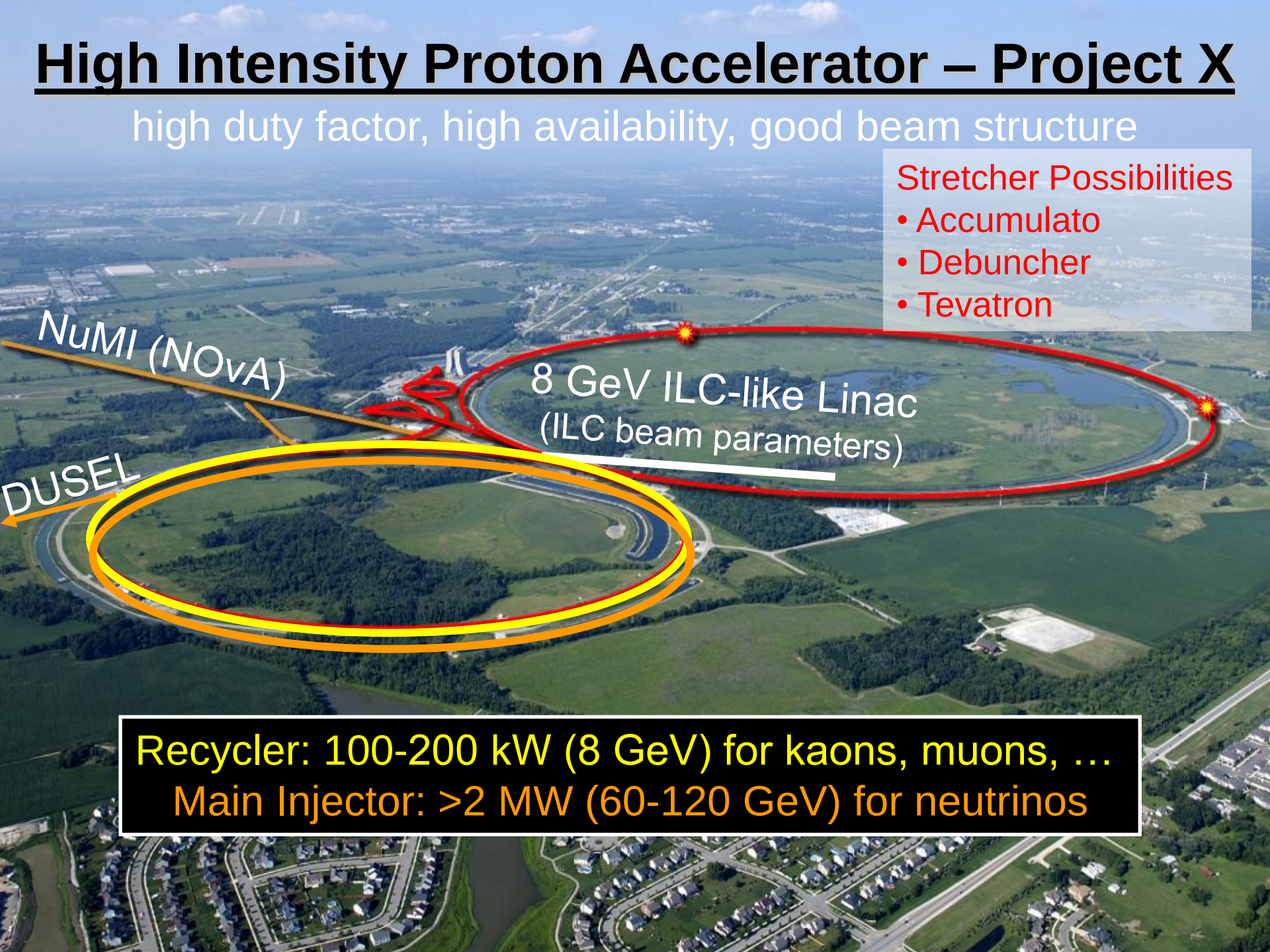
Other Opportunities

- Tevatron Fixed-target programs
  - Precision electroweak studies of ν_μ → e scattering
  - Searches for new physics in the charm system

- Physics with an intense antiproton source including
  - Hyperon CP violation studies
  - Antihydrogen CPT studies

High Intensity Proton Accelerator – Project X

high duty factor, high availability, good beam structure



Recycler: 100-200 kW (8 GeV) for kaons, muons, …

Main Injector: >2 MW (60-120 GeV) for neutrinos

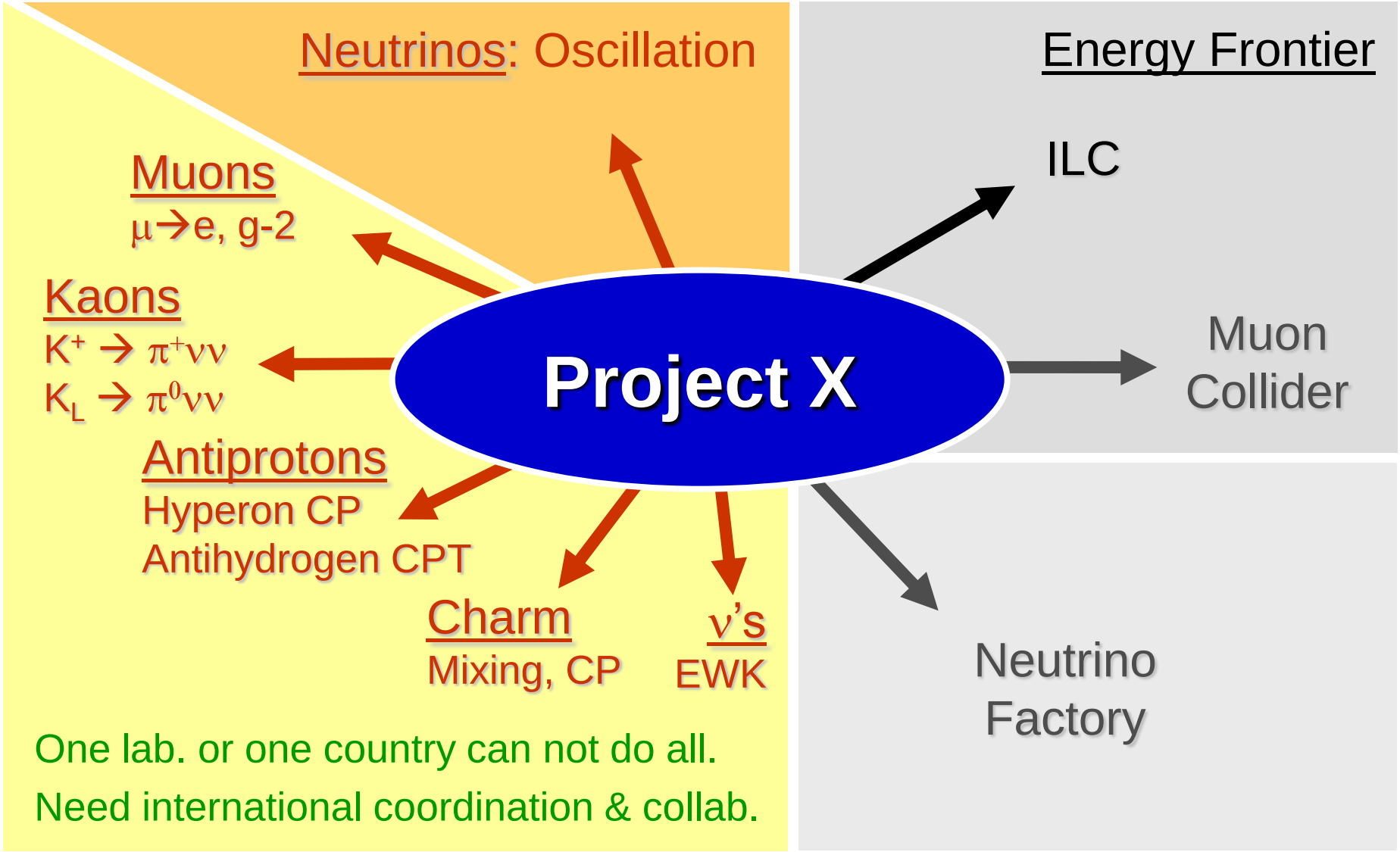
Machine-Experiments Interface Study Group

- Charge
  - involves using the Project X parameters and how to most usefully deliver beam to experiments towards their meeting their physics goals.

- Study Group
  - Chuck Ankenbrand, Jeff Appel (chair), Dixon Bogert, Mike Church, David McGinnis, Eric Prebys, Gina Rameika, Bob Tschirhart

- First meeting on April 18
- Action Item for next meeting (May 2)
  - Generate beam needs tables by experiment for 8 GeV kaon and muon experiments and neutrino experiments in one single document
    - maximum instantaneous rate of protons on target
    - bunch structure
    - average beam rate
    - integrated protons needed
    - length of time needed to accumulate these protons

Conclusions: Opportunities with Project X



The Big Questions by Project X

0. What is the origin of mass for fundamental particles?
1. Are there undiscovered principles of nature:
   New symmetries, new physical laws?
2. Are there extra dimensions of space?
3. Do all the forces become one?
4. Why are there so many kinds of particles?
5. What happened to the antimatter?
6. What is dark matter?
   How can we make it in the laboratory?
7. How can we solve the mystery of dark energy?
8. How did the universe come to be?
9. What are neutrinos telling us?

Fermilab looks forward to an exciting, diverse program for many decades to come.

Developing a Roadmap

for
the accelerator-based program

Fermilab Steering Group (SG)

- Formation of the Group
  - Pier Oddone formed the Steering Group to develop a roadmap for the accelerator based HEP program at Fermilab - Mar. 22, 2007
- Report
  - Internal Report to Pier Oddone - Aug. 7, 2007
  - Final Report - Sep. 18, 2007
  - Presentation to P5 - Sep. 24, 2007
  - Presentation to HEPAP - Nov. 29, 2007
  - Presentation to “New” P5 - Jan. 31, 2008

(P5 = Particle Physics Project Prioritization Panel)

Engaging HEP Community in the SG Process

2nd face-to-face meeting at Fermilab, July 9-10, 2007

Received 17++ proposals

The Steering Group Proposed

Project X,

High Intensity Proton Facility,
if ILC timeline is stretched
significantly

- Enabling world-leading programs
- Aligning with ILC technologies for a shared development effort
- Advancing energy frontier accelerator technology beyond the LHC and the ILC

http://www.fnal.gov/pub/directorate/steering/index.shtml

Project X Accelerator Physics and Technology Workshop

Nov. 12-13, 2007

174 participants from 25 institutions and 4 nations

http://projectx.fnal.gov/Workshop/

- To discuss accelerator physics and technology issues of Project X
- To explore possible areas of overlap and interest between various particle accelerator laboratories and universities

Working Groups

with David McGinnis / Steve Holmes

Working Group	Leaders
Low Energy Linac	Bob Webber (FNAL) Peter Ostroumov (ANL)
High Energy Linac	Sergei Nagaitsev (FNAL) Chris Adolphsen (SLAC)
Recycler	Alex Valishev (FNAL) Thomas Roser (BNL)
Main Injector	Valeri Lebedev (FNAL) John Corlett (LBL)
120 GeV Targeting	Mike Martenes (FNAL) Nick Simos (BNL)

Prepared Document for Accelerator R&D Plan
http://projectx.fnal.gov/RnDplan/

1st Workshop on Physics with a High Intensity Proton Source

Nov. 16-17, 2007

Organized by Fermilab Users and Fermilab

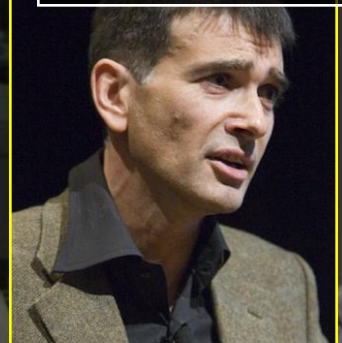
>200 participants from 78 institutions and 8 nations

http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-program.html

Discussion of
Possible Experiments (concepts)

The Big Questions
The Big Questions addressed by Intensity Frontier
Energy Frontier – Intensity Frontier Connection

Intense Proton Facilities
in the world



2nd Workshop on Physics with a High Intensity Proton Source

Jan. 25-26, 2008

Organized by Fermilab Users and Fermilab

>200 participants from 64 institutions

http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-program-2nd.html

Discussed details of possible experiments, their physics impact.
Started developing experimental strategies.

Working with Working Groups

with YKK

Working Group	Leaders
Neutrinos	Bonnie Fleming (Yale) Ed Kearns (Boston)
Muons	Andre de Gouvea (Northwestern) William Molzon (UC Irvine)
Kaons	Doug Bryman (Univ. British Columbia) Bob Tschirhart (Fermilab) Taku Yamanaka (Osaka Univ.)
Antiprotons	Dan Kaplan (IIT) Klaus Peters (GSI)

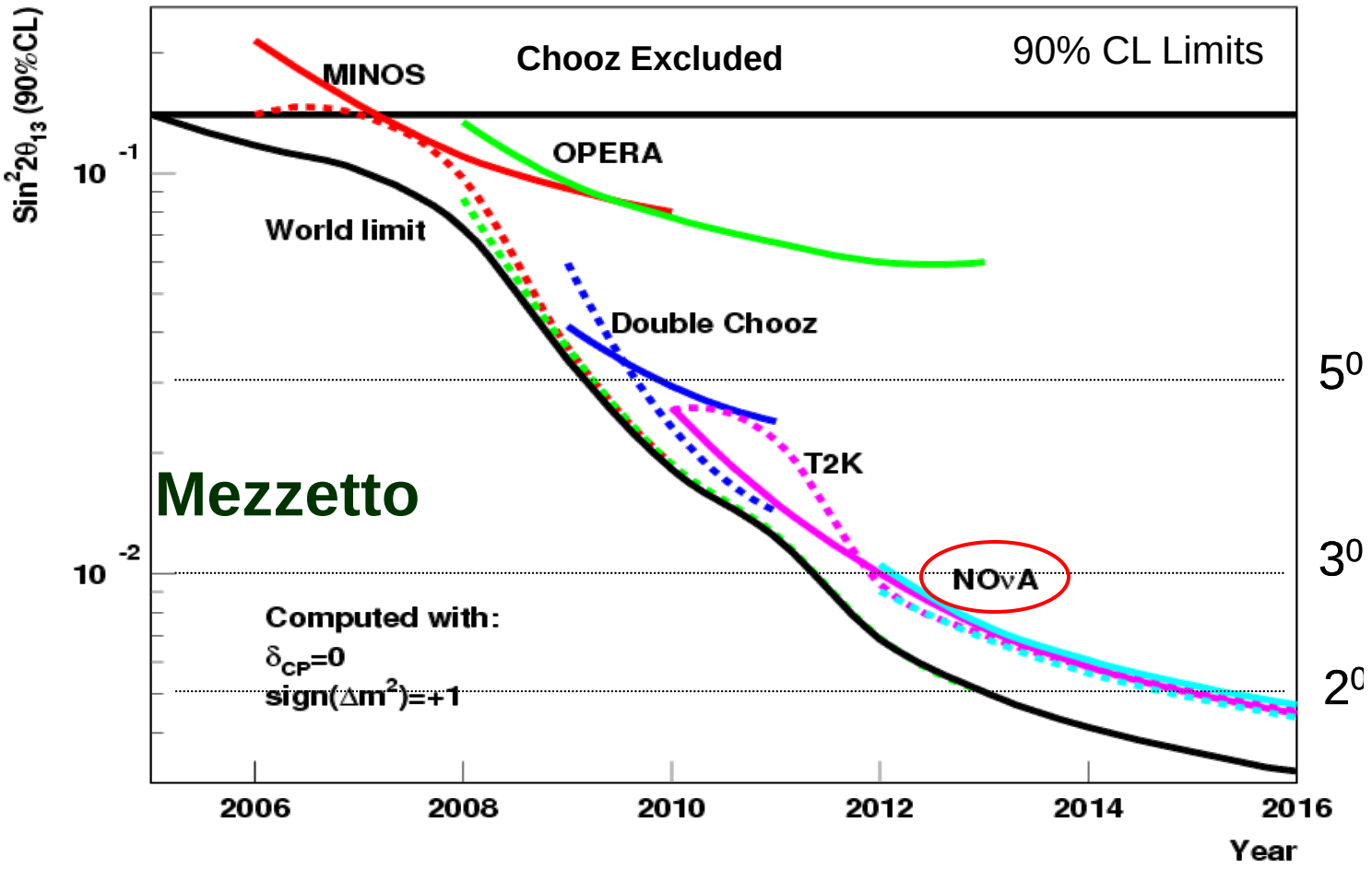
Preparing Golden Book for Physics and Experiments
(still Draft)

http://www.fnal.gov/directorate/Longrange/Steering_Public/P5.html

Other Slides

Outlook of $\sin^2 2\theta_{13}$

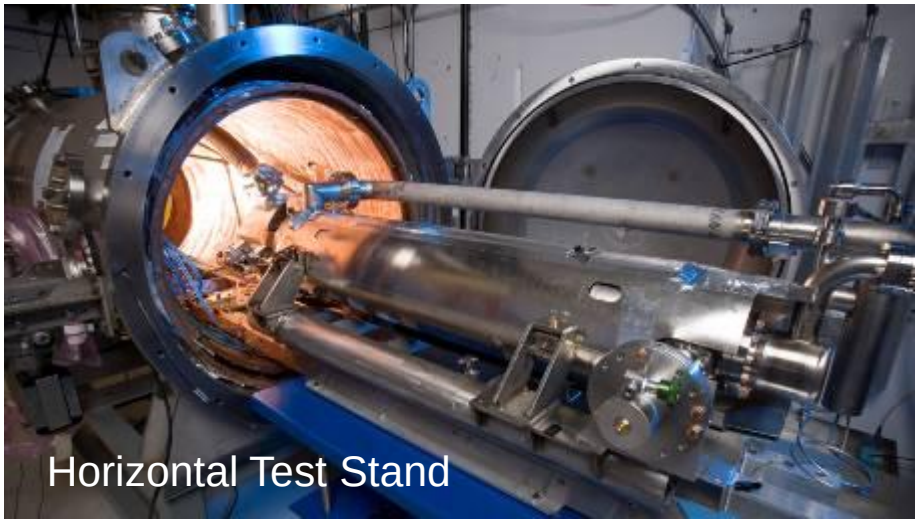
Presented at LP07

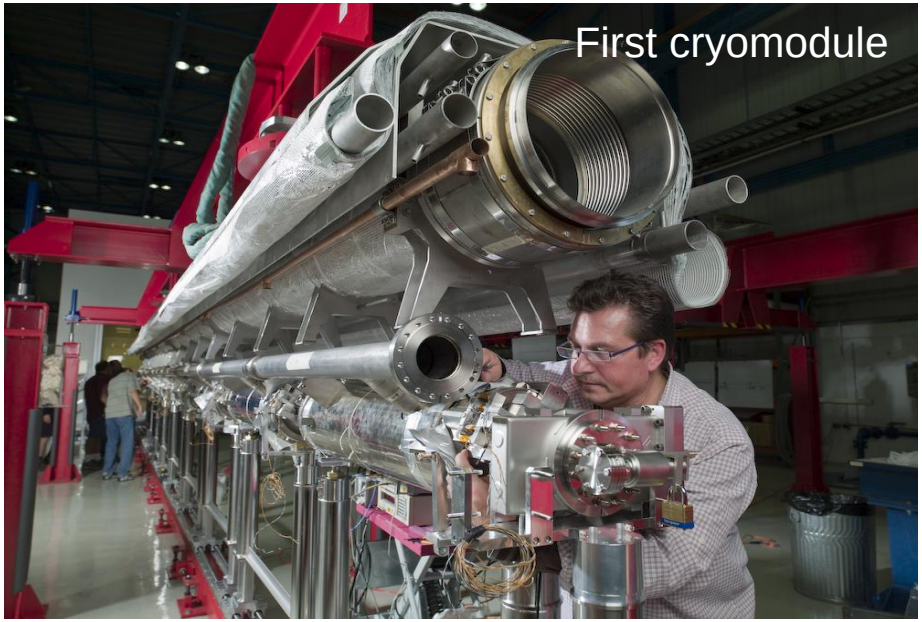


NOvA – sensitive on Mass Hierarchy at large $\sin^2 2\theta_{13}$

ILC technology

at Fermilab



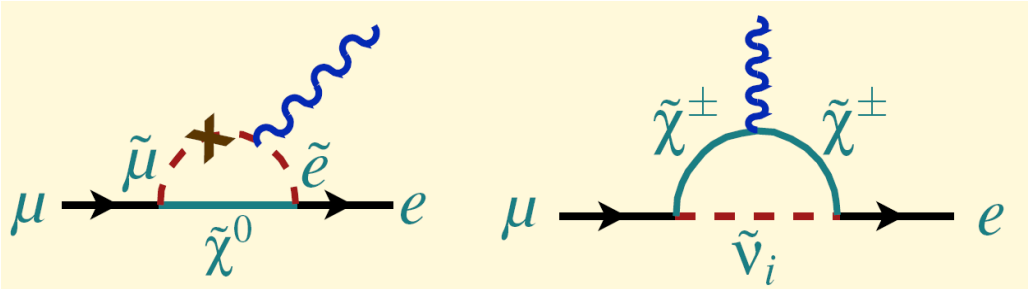


broadly applicable

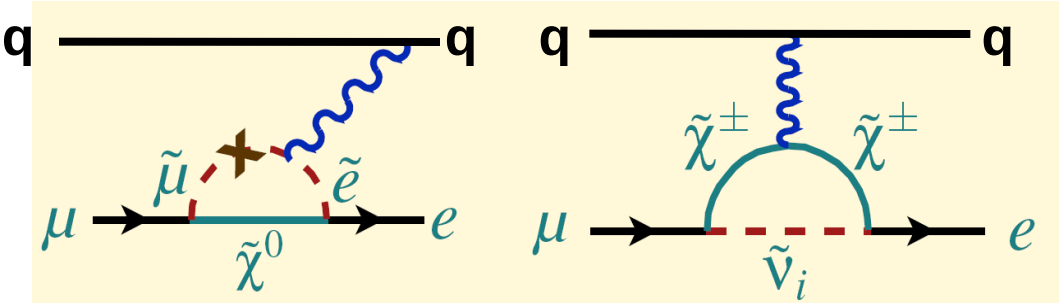
- electron cloud effects
- reliable high gradient cavities
- final focus….

Muons for Charged Lepton Flavor Violation

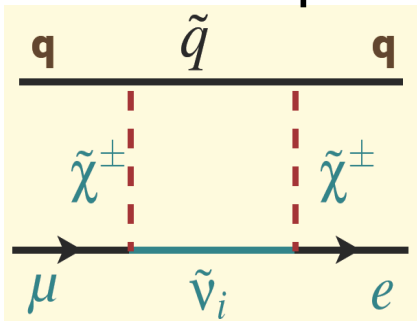
μ → eγ Transition



μ → e Conversion in Nucleus



Sensitive to additional model parameters



other underlying dynamics